Chapter 17

Product portfolio management

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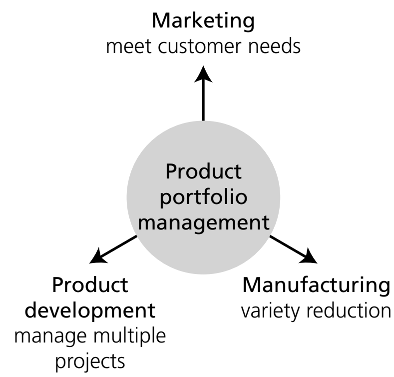
One of the most famous citations in management literature comes from Henry Ford, who reputedly claimed that customers of his Model T could have it "in any colour, as long as it was black". Apart from the weak historical evidence that the 'father' of mass production ever did use these words, this situation did not last long. After a few years, Ford ran into problems when forced to chase the strategy of Alfred P. Sloan, who had restructured General Motors around a divisional organisation and successfully started selling differentiated motor cars. With Sloan's objective of providing a car for every taste and for every budget, product portfolio management entered the modern industrial world.

The problem of product portfolio management can be found in virtually any firm and is indeed a complex matter (Figure 17.1). If you side with marketing, their ideal would be to fit a product to each individual customer. If you listen to product development, they would talk about the nightmare of having to manage more projects simultaneously than one can even remember. If you talk to manufacturing, they would probably remind you of a technique called 'variety reduction program' that was quite successful a few years ago.



17.1 The pressures of product portfolio management

In response to the implications of different organisational functions, this survey on product portfolio management has been based on contributions from different fields, including economics, marketing and operations management. I hope that this heterogeneity will not disrupt the thread of the discussion, which is structured as follows: the next section will discuss the 'front-end' of product portfolio management or, in other words, the marketing perspective. The second section will discuss the 'back-end', which is concerned with the design and development of multiple products. The third section will present portfolio management tools that may help bring the two perspectives together. Conclusions and open issues that ought to be matter for further research will be briefly discussed in the final section.

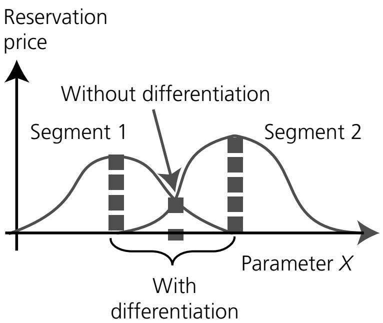
The front end of product portfolio management

Having stated that product portfolio management is a problem for industry, one might wonder about the reasons why firms provide multiple products for their markets. Students of industrial economics are accustomed to explaining this issue under the heading of product differentiation. According to this theory, products may be differentiated either horizontally or vertically.

Horizontal differentiation

Horizontal differentiation exists when, by changing a design variable, utility grows for some customers but decreases for others. Horizontal differentiation is, therefore, related to the particular tastes of customer segments: a car may be given more elegant or more sporty design, and some customers will prefer the former while others will favour the latter. The same happens for perfumes (subtle fragrances as opposed to stronger ones), food (mild as opposed to spicy) and many other products.

An economist would model this situation by saying that the reservation price of customer *x* for product *y* (*i.e.* the price at which the customer would be indifferent either to buying or not buying the product) is given by the utility they gain from their 'ideal' product, minus a function of the distance between this ideal and product *y*. Customers will, therefore, be willing to pay more for a product that exactly matches their taste and less for a product that is more distant. A monopolistic firm providing a single product would, therefore, be forced to lower the price substantially, while catering separately to each market segment allows a firm to keep prices higher (see Figure 17.2).



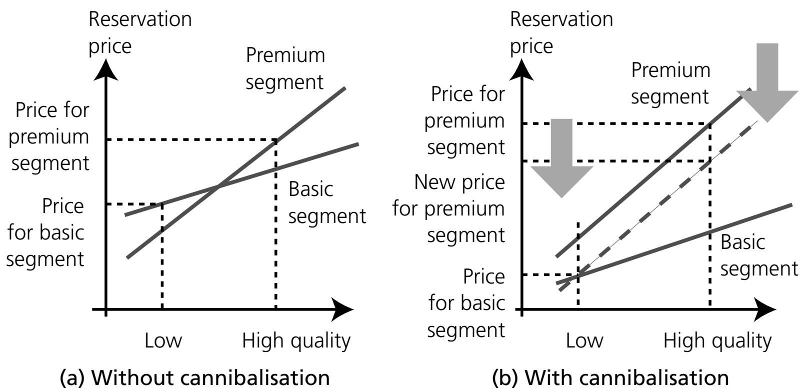
17.2 Horizontal product differentiation can increase prices

When firms are in Chamberlain monopolistic competition (*i.e.* when sellers are many and products are slightly differentiated), or in oligopoly (when competing firms are fewer) theory shows (Tirole, 1989) that, by aiming at separate market segments, there is less competitive interaction among firms, and this decreases downward pressure on prices. This explains why marketing, whose aim is to maximise revenue, would like to sell a distinct product to each customer.

Vertical differentiation

With vertical differentiation, changing the design variable makes utility grow or decrease for all customers in the same direction, though at a different rate. A car with a greater top speed, better fuel consumption, or more comfort will provide more utility to all customers, though some will value the increase more than others. Vertical differentiation, therefore, has to do with performance and quality and the way that this affects customers' willingness to pay.

A firm providing a single high-quality product will be forced to choose between setting a higher price and catering to the 'premium' market segment only (*i.e.* the one that values quality more) or setting a lower price and serving all market segments. This latter option would, however, give the premium customers a deal, since they would walk away with more 'surplus' (*i.e.* the difference between their reservation price, which is equivalent to the utility they gain from the product, and the price they are actually asked to pay). Alternatively, the firm might provide a single low-quality item and serve the 'basic' segment only (*i.e.* the customers who value quality less), but lose revenue from premium customers. In order to increase revenue, the firm could provide a high-quality item at a higher price and a low-quality item at a lower price, thus serving both segments at (or close to) their reservation prices. In doing so, the firm must be aware that it risks cannibalisation of its high-quality products, as shown in the Figure 17.3.



17.3 Vertical product differentiation can decrease prices

Figure 17.3a depicts a vertically differentiated firm, serving two segments without cannibalisation. The figure shows the utility of the two segments as a function of product quality, and the quality levels and prices for the two products it sells. The two utility curves cross, so that the premium segment is willing to pay the required amount for the high-quality product, whereas the basic segment is willing to buy the low-quality product. Neither segment would have any benefit in switching to the other product, since surplus would be negative for them.

Figure 17.3b shows a case with cannibalisation. While the basic segment still buys the low-quality product, the premium segment finds that by buying the low-quality product, they would gain positive surplus, with the fall in price being greater than the fall in utility. In order to avoid cannibalisation, the firm can either lower the price of the high-quality product, or keep the price fixed but increase the quality of the high-end product, or even purposely degrade the low-quality product, so as to place it to the left of the intersection between the two utility curves.

For example, airlines sell seats in economy class and business class at very different prices. However, many firms often save money by making their staff fly economy class and use tricks, such as buying two return 'back-to-back' tickets, in order to avoid Saturday night stayovers. In order to avoid cannibalisation, airlines can discount their business class fares (for example, back-to-back ticketing can be discouraged by pricing business class at less than double the cheapest economy return fare), or act on the parameters that determine service quality. For instance, they can increase the value of business class travel by providing more facilities at the reserved airport lounges. Alternatively, they can degrade the value of economy class travel to business people by doing away with on-board meals: while people travelling for leisure would find little discomfort in eating at a different time, this might be unbearable for someone travelling on a tight business schedule.

The degree to which cannibalisation is present in a specific market is often measured by using Moorthy and Png's (1992) index:

$$R = \frac{\text{size of premium segment}}{\text{size of basic segment}} \left(\frac{\text{valuation per unit of performance of premium}}{\text{valuation per unit of performance of basic}} - 1 \right)$$

which assumes that the market evaluates performance with a linear function. The index goes from zero (if the premium segment is very small or values quality in a quite similar way to the basic segment) to one (if the size of the premium segment is equal to the reciprocal of the ratio between valuations) and tends to infinity (when the basic segment is very small).

The previous discussion has provided the theoretical foundation explaining why, at least in terms of revenue, firms should offer differentiated products to their markets. Of course, reality is slightly more complicated. Apart from the obvious remark that high product variety comes at a cost, in a competitive environment it can also become a 'must-have' feature that all firms provide in order to serve the market, but without gaining significant competitive advantage from it.

With vertical differentiation, as discussed by De Fraja (1996), firms can provide multiple products that will, in the absence of cooperative agreements, compete head-on and develop identical product offerings instead of specialising and each occupying a separate niche. Competition at the same quality levels will, therefore, force price reductions and decrease profits. This behaviour can be observed in most industries (for example, personal computers and cameras), which are generally dominated by companies providing very similar, broad product lines.

With vertical differentiation firms can provide multiple products that will compete head-on and develop identical product offerings, each occupying a separate niche.
(De Fraja, 1996)

This discussion also suggests that niche players, who may reap very good profits from their positioning, cannot emerge out of competitive manoeuvring, but must base their existence on truly inimitable assets or competencies.

A further result is that, when the number of competing firms increases, product differentiation tends to be lower. With an infinite number of firms, the product becomes ever more the commodity at the highest quality level, and price decreases until it reaches marginal cost. On the empirical side, Bayus and Putsis' (1999) study of the personal computer industry shows that product proliferation has not led to reduced competition, and that benefits accruing from increased demand have been offset by higher costs. Though the authors admit that it is not possible to generalise these findings reliably, they note that it should at least be recognised that product proliferation is a double-edged strategy. Kekre and Srinivasan (1990) suggest that firms must handle product proliferation very carefully, so that the cost of variety is kept in control.

Costs of variety are examined in depth by Randall and Ulrich (2001) in their study of the US bicycle industry. They show how the provision of greater variety implies greater costs both in production, since it is harder to exploit economies of scale, and in 'market mediation', since managing the supply chain in order to match fragmented demand is more expensive. They find that the manufacturing technology and the structure of the supply chain chosen by a firm depend on which of the two costs is dominant.

The back end of product portfolio management

The previous discussion should lead to a more critical understanding of management literature, which has in recent years publicised the idea of broadening product lines to the point of serving each customer individually.

Mass customisation in perspective

Strategies such as mass customisation (Pine, 1993) are not *per se* a guarantee of success, since competitive advantage may only come from the capability of executing them more effectively or efficiently than other firms. For instance, one can think of the problems encountered by the now-merged computer manufacturers HP and Compaq when they set out to imitate Dell's make-to-order business model. Pine *et al*. (1993) stress that mass customisation has more to do with a complete overhaul of the internal organisation and culture of the firm than to a simple broadening of the product line. Gilmore and Pine (1997) argue that a mass customisation strategy must be carefully studied if it is to be successful, and it must match customer requirements to the firm's capabilities. In order to support the process, they propose a simple a 2×2 matrix that classifies product variety under the two axes of 'change in appearance' and 'change in product' (see Table 17.4).

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(Pine, 1993)

Change in product	Change in appearance	
	No change	Change
Change	Transparent mass-customisation	Collaborative mass-customisation
No change	Adaptive mass-customisation	Cosmetic mass-customisation

17.4 Product variety for mass customisation

According to this framework, the highest amount of customisation occurs when both the product and its appearance vary. This is labelled *collaborative* customisation, with the producer providing tailor-made changes for customers who appreciate variety but do not find it easy to choose within a very broad offering. The opposite is *adaptive* mass customisation (low levels of change on both axes), in which the firm sells a standardised product that the user can adapt by himself. The other two categories are *cosmetic* (*i.e.* the firm sells a product that is for the most part standard, but contains some superficial variety) and, finally, *transparent* (with customisation being provided without the user even being aware of it). The four categories require a different design of both the products and of the processes that relate the firm to its customers.

Concentrating on the design aspects, masscustomised products generally require the development of a modular architecture, so that product variety may be provided at a low cost by combining components and options at the later stages of the manufacturing process, or even at the user's site. Product architecture is closely related to product variety, not only when dealing with customers individually, but also when the firm designs its products so that components are shared across a broad product line.

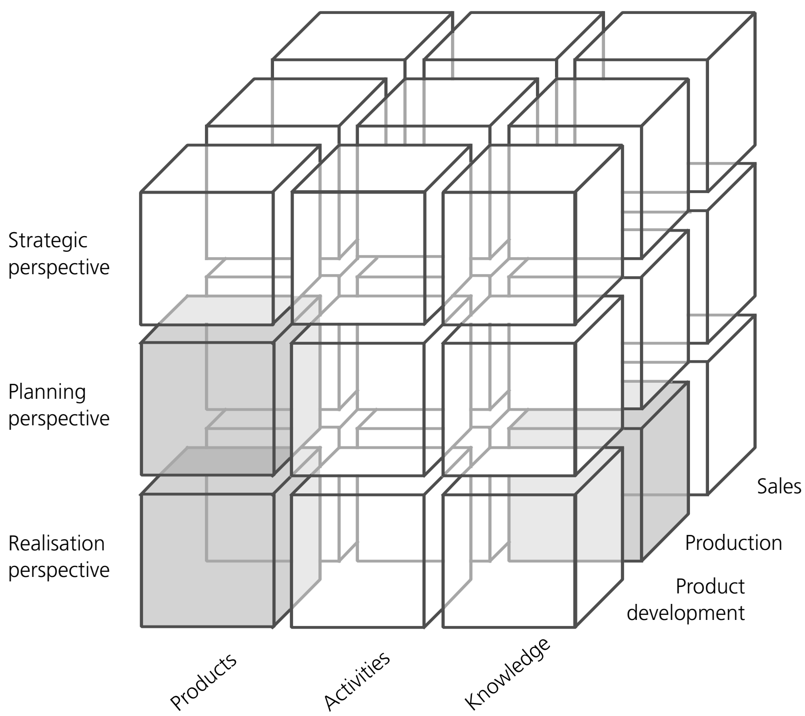
Modularisation

According to a widely accepted definition (Ulrich, 1995), a product architecture is modular when components are functionally independent, *i.e.* when there is a 1:1 mapping among components and functions. Functional independence has a deep impact on the supply chain, since components may efficiently be developed and manufactured separately by different organisations, as well as on the product offering, since variety may be created with greater ease by simply swapping components.

Modularity can affect core functional elements of the product (for example, when combining CPUs, hard disks and graphic cards in a personal computer) or it can be more superficial (for example, when applying covers and loading screen savers, ring tones and games on to a cellular phone). In some instances modularity requires redesign of the manufacturing process, since it is more efficient to move the phases that provide variety and flexibility to its end. For instance, it is well known that Benetton made operations reversal (Lee and Tang, 1998) a key feature of its strategy when it started to knit sweaters before dyeing them. This innovative process enabled Benetton to provide its stores with the right product mix in 'almost real time', and without having to build excessive inventory. A similar approach, discussed by Swaminathan and Tayur (1988), requires the manufacturing of intermediate semi-finished products, termed 'vanilla boxes', and the addition of components according to specific customer orders.

Modularisation is a complex phenomenon that has a wide-ranging impact on the firm and on the supply chain.

Modularisation is a complex phenomenon that has a wide-ranging impact on the firm and on the supply chain. The effects of modularisation can be beneficial, but failing to design the product architecture properly or to understand the required impact on the firm can lead to semi-finished and inconclusive results. To this purpose, Hansen *et al.* (2002) propose a framework for a better understanding of modularisation (Figure 17.5), which has been developed and tested within a number of industrial case studies.



17.5 A framework for understanding modularisation (Hansen *et al.*, 2002)
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The framework shows the three main axes on which modularisation has an impact and that should, therefore, be taken into account when dealing with this kind of strategy. The first axis deals with the temporal horizon, which ranges from a strategic level (*i.e.* defining goals and designing architectures) to a planning level (*i.e.* methods, procedures, plans, *etc.*) down to actual realisation. The second axis deals with the three corporate functions that are principally involved, *i.e.* product development, production and sales. The third axis is based on the widely accepted hypothesis that product architecture is closely related to the organisational structure of the firm, which can be described both in terms of its business processes (Henderson and Clark, 1990) and its knowledge structure (Sanchez, 2000). Accordingly, this axis represents the impact modularisation has on the product, on activities and on knowledge.

The framework in Figure 17.5 is used by Hansen *et al.* to show concisely the way the companies they studied have dealt with modularisation (for example, they insert comments on activities being observed in the appropriate cells). However, this framework could be used as a three-dimensional checklist that management might use to assess the comprehensiveness of the modularisation strategy used by the firm.

A 'module' (or 'chunk') may be viewed as a self-contained subset of components having a defined interface that connects it with other modules.

The design of modular products is an important strand of engineering design research, since it is tightly linked with the problem of embodying a functional structure in a physical assembly of components, which is in turn central to the engineering design process. For instance, Riitahuhta and Pulkkinen (2001) have developed a systematic approach enabling companies to develop highly configurable products based on modular architectures. They distinguish among four levels of modularity, which can be *assembly based* (with modules designed in different sizes, allowing a limited degree of customer-specific product configuration), *function based* (with modules designed on the basis of functionality, so that products may be customised to a greater extent), *platform based* (which introduces a separation among standard components and customer-specific ones) or, finally, there can be *dynamic* modularisation, in which modularity is also designed in view of the product family lifecycle.

In this context, each 'module' (or 'chunk') is viewed as a self-contained subset of components having a defined interface that connects it with other modules. The reasons for which a specific set of components should be selected to form a module may be disparate and are often conflicting. The analysis of these trade-offs and the consequent decision, therefore, requires attentive evaluation by the designer. For instance, modules may be formed in order to allow a wide product range to be generated through combinatorial variety, but other important criteria may be functional interdependence among components, technical issues (for example, energy efficiency, safety, and reliability), flexibility in use (for example, the ease of providing add-on accessories or component upgrades) and ease of operations (*i.e.* technological or economic aspects associated with sourcing, manufacturing, assembly, maintenance and recycling).

Modules may be formed in order to allow a wide product range to be generated through combinatorial variety.

Methods for defining modules are manifold (Breidert, 2003) and include analysis of the functional schematic of the product (Stone *et al.*, 1998; Holta *et al.*, 2003), block-diagonal rearrangement of matrices representing interactions between components (Pimmler and Eppinger, 1997; Huang and Kusiak, 1998; Lanner and Malmqvist, 1998) and algorithms operating on system-theoretic representations of component relations (Gaso and Otto, 2003). Multiple criteria evaluation of modules and the relationship between module definition and the management of technology are covered by Cantamessa and Rafele (2002).

Platforms

The provision of product variety is often based on the concept of platform-based product development, for which a fundamental reference is the textbook by Meyer and Lehnerd (1997). Platform strategy has been associated with the success of firms in many different industries, such as consumer electronics (for example, Sony's family of Walkman cassette players), watches (for example, Swatch) and automotive (for example, the strategy adopted by Volkswagen in the 1990s across its four main brands).

Product platforms have been defined as intellectual and material assets shared across a family of products (Robertson and Ulrich, 1998). This rather broad definition goes beyond the "physical" idea of a platform as a common architecture and set of components. In this way, it covers related but different interpretations that have been given to the platform concept. For instance, Clark and Wheelwright (1993) use the term platform to describe next-generation product development projects, while automotive manufacturers define as 'platforms' those organisational units that are in charge of developing component platforms.

The provision of product variety is often based on the concept of platform-based product development.

In essence, platform-based product development consists of configuring the product development pipeline in a two-tier structure. Platform projects are large-scale projects whose main goal is to create a technological basis and/or a shared set of components. For a given amount of time, the firm may then base a set of smaller (in terms of cost and development time) derivative product development projects on this platform. This arrangement has four main advantages.

The first and most obvious advantage is that platforms allow a high degree of component sharing among product versions, which can lead to significant economies of scale in manufacturing and purchasing.

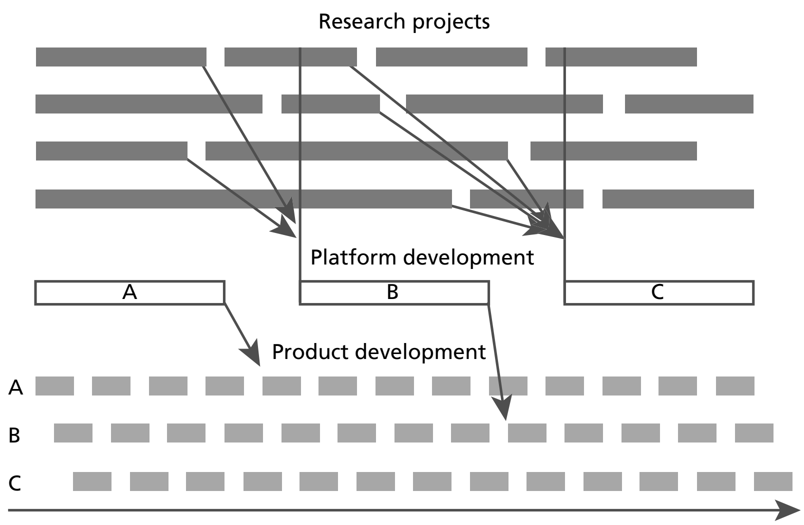
Second, the development of a platform usually requires significant investment, but it allows firms to perform a stream of derivative projects at low marginal cost and with reduced time-to-market. In principle, the overall development cost of the platform project and of its derivatives should be less than what would have been spent with on an equivalent number of independent projects. By enabling quick execution of derivative projects, platforms allow firms to react more rapidly to changes in the market.

Platform projects can be used to validate a set of new technologies, individually and with respect to their interoperability, and to create the know-how needed to deploy them in derivative product development.

The third advantage is that alternating platform and derivative product development projects can help the firm achieve a less markedly cyclical performance. In terms of costs, a platform-based product development portfolio can be designed with a level resource utilisation profile, thus reducing the need for changes in the work force (or avoiding inefficient troughs and delay-inducing peaks in the overall work load). In terms of revenue, the competitiveness and profitability of derivative products will decline over time, since these will be based on an ageing platform. If platforms associated with different product families are staggered in time, the firm will exhibit a balanced product portfolio with respect to age and profitability.

The fourth and last advantage is that a platform-based product development strategy tends to keep more innovative activities separate from the less innovative ones. As shown in Figure 17.6, firms can use platform projects to transfer results from research into product development. This approach gives research projects a clearer objective ("we must finish project *X* by month *K*, so as to feed its results into platform project *Y*") and allows them to test new and riskier technologies within a sufficiently large-scale project that, not being directly pulled by the market, is not generally subject to an exceedingly tight schedule.

Platform projects can be used to validate a set of new technologies, individually and with respect to their interoperability, and to create the know-how needed to deploy them in derivative product development. Following terminology used at Hewlett-Packard, this is often called a 'pizza-



17.6 Platform projects transfer results from research into product development

bin' approach. At the same time, by taking the more innovative design tasks out of derivative product development, engineers are discouraged from over-designing individual products ("why don't we try technology *X* in this new product *Z*?"), which results in increased cost and lead time, often with dubious benefits.

This separation of the more innovative activities from product development has been studied by Krishnan and Bhattacharya (2002), who analyse and criticise the pizza-bin approach. They discuss whether basing product development only on a proven technology risks leading the firm to develop inferior products. Instead, they argue, it might be profitable to defer commitment and concurrently both develop products and validate the unproven technology. This may be done either by allowing two parallel product development processes (one per technology), or by overdesigning the product so that it may use both technological options. The choice between these alternatives depends on the added cost and on the estimate of the profitability gap shown by the two technologies.

The analytical model developed by Krishnan and Bhattacharya shows that, if the estimate of mean added profitability for the unproven technology is low, the pizza-bin approach is appropriate. If the mean estimate is high and the variance is low, they recommend the parallel approach, whereas high mean and variance make the overdesigned approach better, since this approach moves the commitment point to the latest point in time, when uncertainty regarding the new technology will be minimal.

When using platform-based product development, the evaluation of performance on *a per project* basis can be misleading, since there are dependencies among products and/or platforms and derivatives. Projects must therefore be managed with respect to the overall impact on the product pipeline and not individually. Meyer *et al*. (1997) discuss the problem of aggregate-level R&D metrics and make a distinction between the development of initial platform architectures, platform extensions (*i.e.* enhancements to subsystems that do not modify the platform architecture) and platform renewals, in which the architecture is altered. They propose measures for the efficiency of a platform (*i.e.* the degree to which a platform allows economical development of derivatives) and effectiveness (*i.e.* the degree to which derivatives produce revenue with respect to their development cost, where the use of revenue instead of profit is due to the practical concern that it is difficult to obtain reliable estimates of product-specific costs).

$$\text{Platform efficiency} = \frac{\text{average R\&D cost for derivative products}}{\text{R\&D cost spent for the platform}}$$

Platform efficiency is defined by the ratio between the average R&D cost (or development time) for derivative products over the R&D cost (or time) spent for the platform. A low value of this ratio implies that the platform is able to sustain economic development of derivatives, and *vice versa*. In the case study they present, Meyer *et al*. record values of platform efficiency around 0.1, though this figure cannot be generalised. Platform effectiveness is given by total sales of a platform and its derivatives over the total development cost. In this case, higher values of this indicator imply better performance. They recommend using these indicators both statically, in order to compare performance of different platforms, and dynamically, in order to observe the degree to which a platform is still able to sustain the low-cost development of derivative products and/or to generate meaningful revenue.

The management of multiple products through component sharing has attracted significant interest from researchers, since common sense and industrial experience make it apparent that platforms cannot be a universal answer to product strategy, for there must be trade-offs to be considered. For instance, excessive component sharing across brands in the automotive sector has often been criticised by consumers and the press, as in the case of Ford components being used in Jaguar cars, or Volkswagen's use of the same platform for widely different models.

In this context, Krishnan *et al*. (1999) present a model for the optimal design of a product family, with differentiation restricted to a single performance attribute, and in which both development cost and revenue are considered. They hypothesise that the firm develops the platform first and then starts to develop products with increasingly improved performance by progressively adding new components or by adapting/improving components from previous variants. They identify the main trade-off decision as that between the increased revenue due to a rich product line (coming from more sales and/or greater profitability) versus the development costs, which depends on both the degree of component sharing achieved by the platform and the number of product variants.

The assessment and design of a product line should be made on profits, and in aggregate and not on a *per product* basis.

Ramdas and Sawheny (2001) expand the traditional literature on product-line definition in order to discuss trade-offs when components are shared among products. They develop a mixed-integer linear programming model and discuss a few insights resulting from its application in a watch manufacturing company. The discussion of revenue effects due to product variety is particularly interesting. These effects are classified in the three categories of *demand expansion* (*i.e.* sales to customers who would not have bought a similar product at all), *competitive draw* (*i.e.* sales to customers who would have bought a product sold by a competitor) and *cannibalisation* (*i.e.* sales to customers who would have bought a different product sold by the same firm). Ramdas and Sawheny argue that assessment and design of the product line should be made on profits, and in aggregate and not on a *per product* basis. For instance, it may be unprofitable to prune out low-selling items, since these may actually be gaining sales from demand expansion and competitive draw and/or have little additional cost. Conversely, it is possible to have unprofitable high-selling items, either because of their high cost, or simply because they sell primarily through cannibalisation.

The paper by Desai *et al*. (2001) is also quite appealing because of the conceptually simple setup it is based on, which allows us to gain some interesting insights on the problem of product differentiation based on shared components. The model views a two-segment market (high and low, or H and L) and two components that determine product quality, which can be designed in two quality levels (*premium* or *basic*). For simplicity, it is assumed that the second component must be designed according to the segment being targeted, so that three possible configurations emerge (Table 17.7). They assume that customers evaluate quality through a linear combination of component quality, while the manufacturing cost of components varies quadratically with quality. The setup is modelled as a three-stage game in which the manufacturer selects the configuration and the design effort for each component, then it sets prices in order to maximise profits, and finally customers decide whether, and which product, to buy.

Segments	Configurations		
	Unique	Premium common	Basic common
High	Premium Premium	Premium Premium	Basic Premium
Low	Basic Basic	Premium Basic	Basic Basic

17.7 Product differentiation based on shared components

At first, the analysis shows some interesting facts with regard to revenues alone. If compared with the unique design, where there is no component sharing, the premium common design might not necessarily grant higher prices and revenues, even though it leads to a better basic product. This can happen because the quality gap between the two products becomes narrower and the firm must be careful to avoid cannibalisation. So, the additional revenue gained from the higher price that can be asked for the basic product might be more than offset by the lower price that must be applied to the premium product. When comparing the basic common design with the unique, the optimal price for the basic product is the same, but the lower quality premium product must be sold at a lesser price, which causes a fall in revenue.

Concerning profits, the optimal configuration depends on a number of parameters. The premium common design may be more profitable than the unique depending on the trade off between three elements: the previously discussed increase or decrease in revenue, the increase in cost due to using the more expensive component in the basic product and decrease in cost due to economies of scale. The basic common design may be more profitable than the unique depending on the interplay of two effects: the fall in revenue and the cost savings due to the lower quality of the component being used and to greater economies of scale. In addition to these insights, Desai *et al.* study the profitability of making individual components common and find that they should be ranked according to the index

$$I = \frac{\text{cost coefficient of quality}}{(\text{weight in quality evaluation function})^2}$$

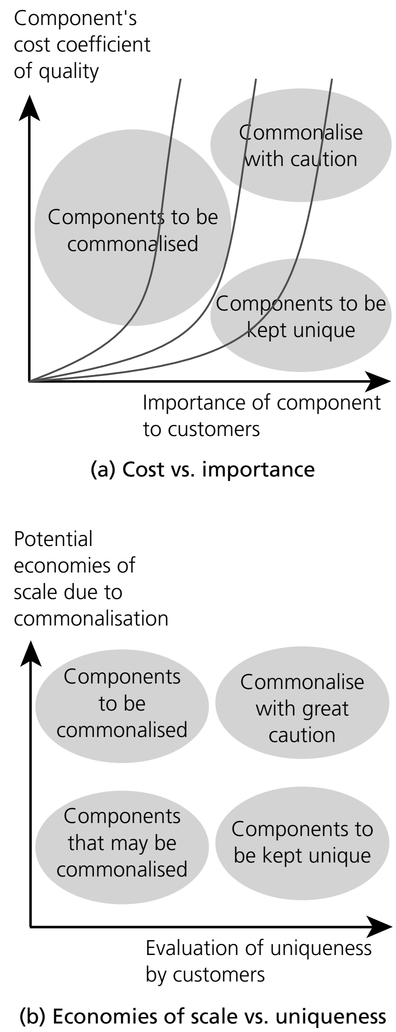
In other words, components to be shared are the ones for which manufacturing cost varies more with the quality level and/or the ones that are less important to customers in their evaluation of product quality. It is interesting that the index does not depend on the way with which the two market segments evaluate product quality. This index may be applied in practice to map components on the two axes present in the ratio (Figure 17.8a). This map can be used instead of, or in conjunction with, qualitative mapping techniques that are often used in industry (Figure 17.8b). Other criteria for component sharing (Fisher *et al.*, 1999) include the assignment of components to a spectrum that ranges from the purely aesthetic (maximum variety is required) to the purely functional (maximum sharing would instead be preferable), or the distinction among components that have a strong influence on perceived quality (customer utility can be thought to vary quasi-linearly with performance) and those that do not (with customer utility more or less following a step function, with no utility below a threshold level of performance and a constant utility above).

In contrast to Desai *et al.*, Krishnan and Gupta (2001) instead take the platform and the associated list of shared components as a given and study whether this sharing is beneficial or not. They argue that platform-based product development may have benefits, but entails costs associated with the overdesign of low-end products (or the underdesign of high-end ones) and with opportunity costs that arise by delaying market launch. They develop a model in which a firm must serve the needs of two customer segments (basic and premium) with four product planning options:

- a platform-based approach (P1), where the platform matches with the low-end product, and a second project adds features leading to the high-end product;
- the independent development of the low-end and the high-end product (P2);
- the development of the low-end product only (P3), to be sold to both segments;
- the development of the high-end product only (P4), to be sold to both segments.

They argue, based on an analytical model of revenues and costs, that the optimal choice among the four options depends on two main parameters: the degree of market diversity, measured by using the previously introduced ‘degree of cannibalisation’ by Moorthy and Png (1992), and non-platform economies of scale (*i.e.* the degree to which components that do not belong to the platform can benefit from economies of scale).

The main findings of Krishnan and Gupta are summarised in Table 17.9. With respect to these two parameters, platform-based product development is profitable for ‘intermediate’ products because of revenue and cost issues. From



17.8 Mapping components

17.9 Economies of scale for platform-based development (Krishnan and Gupta, 2001)
Management Science

Non-platform economies of scale	Market diversity		
	Low	Medium	High
Low	Low-end product only	Product family, with or without a platform	High-end product only
Medium	Low-end product only	Platform-based product family	High-end product only
High	Low-end product only	Low-end product only	Low-end product only

the side of the market, when market diversity is low the firm is better off with a low-end product only (which costs less to develop), whereas a high degree of market diversity makes it advisable to develop the high-end product only, since this caters better to the needs of the premium segment and avoids the cost of developing an additional low-end product. From the side of view of costs, high non-platform economies of scale can make it profitable to forgo the platform approach and develop the low-end product only, so as to exploit these economies of scale to a fuller extent.

Krishnan and Gupta also explore the timing of product introduction, in which the main trade off is between the delayed revenues due to the delayed launch and the reduced cannibalisation when only one product is on the market. The parameter that mostly determines the optimal choice is the ratio between the firm's discounting factor (which is related to profits) and the customers' (which instead is related to surplus). In essence, this ratio measures the relative impatience of the two agents. They show that a greater discount factor for the firm suggests the simultaneous launch of the two products, so as to speed up revenues, whereas greater impatience from customers makes sequential launch optimal (Table 17.10).

17.10 Discount factors and market diversity (Krishnan and Gupta, 2001)
Management Science

Discount factor	Market diversity		
	Low	Medium	High
Discount factor greater for the customer	Low-end product only, or family launched sequentially without platform	Platform-based family launched sequentially	Platform-based family launched sequentially
Discount factor greater for the firm	Low-end product only, or family launched simultaneously without platform	Platform-based family introduced simultaneously	High-end product only

Robertson and Ulrich (1998) propose a practical method for planning product platforms, with the objective of finding the right trade-off between distinctiveness, which is a driver of revenue, and commonality, which instead tends to reduce cost. Their framework is based on three 'plans', namely the *product* plan (in which the firm defines a portfolio of products and variants along with launch dates and target segments), the *differentiation* plan (in which the firm identifies 'differentiating attributes', gives them a score and then defines how each product in the product plan should relate to such attributes) and the *commonality* plan (in which the firm identifies component modules, collects data on fixed and variable costs, and then assigns them to each of the products in the plan). The idea behind the approach is to revise these three plans iteratively until the decision-maker reaches a sufficient degree of consistency.

Multiple project management

Even though companies engaged in product development generally operate more than one project at the same time, multiple project management (MPM) has received scant attention from academics, probably because of its formidable difficulty. From the perspective of operations research, multiple project scheduling under resource constraints involves a very high computational complexity and for practical purposes requires heuristics to be solved, a topic that is often scarcely appealing to academics and is more likely to be found in practitioner-oriented literature.

Multiple project scheduling under resource constraints involves a very high computational complexity and for practical purposes requires heuristics to be solved.

An exception is the paper by Yang and Sum (1997), who assume a dual-level structure with a programme manager overseeing a number of projects, each led by a project manager. They study due date, resource allocation, project release and activity scheduling rules together and show that, at an individual project level, there is a very important trade-off between the due date negotiated with the customer and the resources allocated to the project. This trade-off obviously affects the project, but can have an impact on the other projects as well, since a late and underresourced project will compete desperately for extra resources, thus disrupting the scheduling.

They also show that the decision on project release dates is very important. It is often better to keep a project out of the system for some time, rather than having it compete with other projects and ending up with resources too thinly spread. This can be even more critical in the case of multiple-resource problems, because there is a greater chance that activities may be held up waiting for the right combination of resources to free themselves.

Product portfolio management is reviewed by Payne (1995) from a practice-oriented viewpoint and under five main perspectives (capacity of resources, complexity, conflict management, commitment and context). Drawing from personal experience, it can be argued that a critical issue in MPM, which is often overlooked in the literature, is the management of simultaneous projects that may be differ widely with regard to project size, skills required and urgency.

The interactions among different projects due to resource sharing have also been studied by Adler *et al*. (1995), who suggest looking at the product development function as a process, rather than as a collection of individual projects, and using queuing network theory as an analytical approach. The main issue they raise is that firms generally approach project management on a *per project* basis and do not attempt to get the 'big picture', with an objective assessment of the resources required by the active project portfolio with respect to the amount that is effectively available. Queuing network theory fits in well, since one of the main tenets of this approach is to highlight mismatches of this kind and to trace effects in terms of delays in task completion. They show that, even though it is generally considered sound management to use resources at capacity, this causes delays in task processing that may grow out of control, except for low values of task variability.

These results are fairly standard in industrial engineering, but have seldom been applied to product development. Apart from the direct application of their method, Adler *et al*. use the results to emphasise the need to monitor the existence of bottleneck resources closely, by aggregating projects and calculating resource workload profiles, and to take measures so that they are adequately staffed.

Another suggestion is to cap the number of projects in the firm to the point of mimicking a just-in-time 'pull' system in which the start of a new project is authorised only when the overall number of projects falls below a given threshold. Another measure that could be introduced in order to reduce waiting time further is cross-training and pooling of resources (conversely, one could devise an analogy of a cell-based manufacturing system and specialise resources with the criterion of assigning tasks with similar duration, in order to reduce variability).

MPM is complex because interactions between projects are not only associated with shared resources, but also with information transfer.

MPM is complex because interactions between projects are not only associated with shared resources, but also with information transfer, for instance when one project serves as the basis for a second one. Nobeoka and Cusumano (1995) discuss this problem on the basis of a survey carried out in 10 American and Japanese automotive manufacturers. They define four typologies of design interaction: carrying out a new design without any interaction, rapid design transfer from a base project to a new one (similar to concurrent engineering), sequential design transfer among projects related to different product lines (in which the new project starts when the base project is ended), and design modification (similar to the previous case, but with both projects related to the same product line).

Empirical results show that rapid design transfer is the more effective strategy for engineering man hours. Rapid design transfer, however, must meet some requirements if it is to be effective. These are part technical, related to the features of the technological platform that must serve both projects, and part organisational, associated with the definition of senior roles and responsibilities, the planning of projects in order to exploit synergies and minimise rework, and the management and sharing of design knowledge and design rationale.

It is well known that project management should be associated with rigorous methods of planning, scheduling, budgeting and controlling projects.
(PMI Standards Committee, 2000)

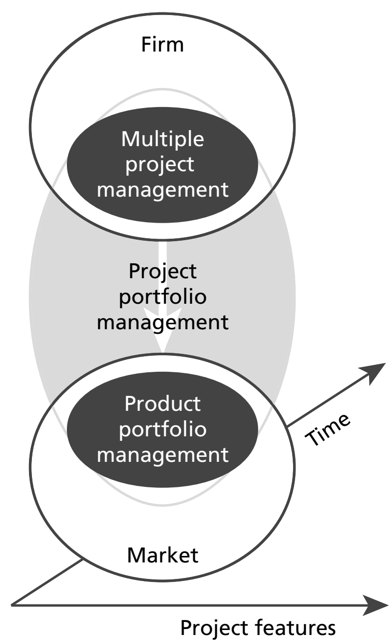
It is well known that project management should be associated with rigorous methods of planning, scheduling, budgeting and controlling projects (PMI Standards Committee, 2000). Marle and Bocquet (2001), go beyond the PMI guidelines to propose a method for MPM in the context of new product development. Their approach is based on decomposition (of the program into projects, and of these into smaller activities), assignment (of resources and responsibilities) and state management by the resources endowed with responsibilities.

Bringing the two together: project portfolio management

Readers may have noticed that a theme often raised in the previous sections is that the firm must be able to carefully pick the projects it engages in, so as to ensure profitability both from the side of revenue and that of cost. The management of the project portfolio is a key element of strategic decision-making in the firm.

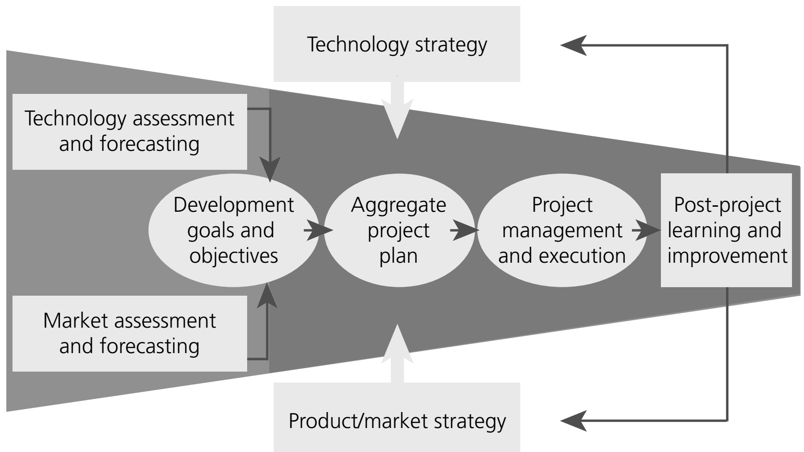
The strategic role of project portfolio management

Project portfolio management (PPM; not to be confused with product portfolio management) determines the allocation of scarce resources across time and project scope, a concept that is represented graphically in Figure 17.11, showing how PPM sets the basis for product portfolio management and multiple project management.



17.11 Project portfolio management

It should be noted, however, that setting the basis does not mean that the two latter are strictly *part of* the former. The strategic role of PPM (or aggregate project planning) in the product development process has been amply discussed by scholars. For example, Wheelwright and Clark (1992) make it a key element of product strategy, as in Figure 17.12.



17.12 The strategic role of product portfolio management
Adapted with the permission of The Free Press, a Division of Simon & Schuster Adult Publishing Group, from REVOLUTIONIZING PRODUCT DEVELOPMENT: Quantum Leaps in Speed, Efficiency, and Quality by Steven C Wheelwright and Kim B Clark. © 1992 by Steven C Wheelwright and Kim B Clark. All rights reserved.

Since the product development process is nearly universally operated on the basis of projects, it may safely be claimed that strategic decision making in this context is coincident with PPM. In broader terms, the implementation of an R&D strategy must go through the analysis and the redesign of the firm's project portfolio, so that projects that match with strategic needs are kept alive and assigned sufficient resource, while the ones that do not are pruned out.

As surveys have often shown, most companies do not manage their project portfolio at all, or do so informally and without a structured process. Not having a systematic approach for PPM leads the firm to have too many projects at the same time, since it is always easy to start a project ("let's try it out"), but it becomes very difficult to terminate one. Resources become overloaded and thinly spread out among projects that are widely different technical content and strategic fit. Table 17.13, after Cooper *et al.*, (1998), provides a summary of these consequences.

Techniques for project portfolio management

PPM consists in the assignment of a limited amount of resources, human, technical and financial, to a set of projects, each of which can be characterised in terms of expected economic value and risk, so as to obtain an acceptable

Not having a formal PPM approach implies	Immediate consequences	Final consequences
Reluctance in killing projects, too many approved projects, unclear objectives	Too many projects, resources thinly spread, low execution quality	Long lead times, high percentage of unsuccessful projects
Weak go/kill decisions	Too many mediocre and low-level projects. Insufficient resources assigned to important projects	Too many projects with weak innovative content. Few projects able to provide competitive advantage
No objective selection criteria. Projects selected on emotive or political basis	Wrong projects selected	New product failures
No strategic criteria for project selection	No clear direction for the project portfolio. Insufficient synergies among projects	New products do not support the firm's strategy. R and D resources used inefficiently

17.13 The consequences of no portfolio approach
Cooper *et al*. (1998) *Portfolio management for new products* – table reproduced with permission of Dr. Robert G Cooper

overall result. This definition is very similar to the problem of managing a portfolio of financial securities, even though there are important differences, such as the synergies and exclusions that may exist among projects.

PPM can be discussed both as a process and with respect to the techniques that it uses. In the first view, there is a standard classification between bottom-up and top-down PPM. In the former, projects are proposed from the lower tiers of the organisation and the program manager must decide on the acceptability and the funding of each proposal. In the latter, the program manager assigns budgets to organisational units and/or to project categories (for example, research vs. development and product vs. process) and delegates decisions.

The bottom-up approach allows top management to have a better view of the project portfolio, but requires greater effort to create a tight fit with the firm's strategy and to manage the selection process. The design of PPM as a process has been tackled by a number of authors, such as Cooper *et al*. (1998). Archer and Ghasemzadeh (1999) propose a framework process for PPM based on seven phases that bring together, in a coherent way, a number of well-known best practices. The phases are pre-screening, individual project analysis, screening, portfolio selection, portfolio adjustment, project execution and stage-gate evaluation.

Stummer and Heidenberger (2003) propose a PPM procedure that considers project interdependencies, based on the three phases of screening, multi-objective optimisation and search for Pareto-optimal portfolios and, finally, project selection. Nidamarthi *et al*. (2003) present a portfolio management methodology used at ABB for analysing cost and revenue of individual products within a product family and for optimising overall profitability.

Conversely, if one looks at PPM from the perspective of techniques, these can roughly be classified in the following categories: financial methods, optimisation methods, multi-criteria methods, and mapping methods.

Financial methods

In principle, product development projects should be evaluated according to the Net Present Value of the relevant cash flows, including development and manufacturing costs and revenue.

In principle, product development projects should be evaluated according to the net present value (NPV) of the relevant cash flows, including development and manufacturing costs and revenue. This means that it is incorrect to consider expenses that have already been allocated and cannot be reversed (sunk costs). Cash flows should be discounted at a rate appropriate to the risk inherent in the project, which is not easy to determine, although many firms incorrectly define a single internal cost of capital and apply it to all of their activities. One way out of this problem is to use indexes that separate development cost, contributions from sales and technical and commercial risk. An example is expected commercial value.

Such indexes are fairly easy to use, but neglect interactions that often exist between projects. The case where the results of a first project provide the basis for the development of a second project is particularly interesting. In this case, the decision whether to activate the second project or not can be deferred and made after having observed the results of the first. This deferral reduces risk and provides the first project with an 'option value' that has to be added to its intrinsic value (*i.e.* the value it would have if there were not further decisions to be made at its end).

The term 'option' is a reminder of the financial instruments having the same name. Specifically, there is an analogy with European call options, which give their owner the option, but not the obligation, to buy a security at a given price on a given date. The option will be exercised if it is advantageous (*i.e.* if the security is traded above the exercise price). In order to distinguish the two uses of the word 'option', the application of this concept to concrete activities is often termed 'real option'.

The evaluation of real options can be carried out by exploiting the analogy with financial options, for instance by using Black and Sholes' pricing formula.

Owing to the difficulty in correctly evaluating discount rates, more sophisticated approaches have also been developed, such as the replicating portfolio method (Copeland and Antikarov, 2001). Since projects usually have discrete outcomes, a more straightforward, though approximate, computation of real option values may be based on standard decision trees.

Optimisation methods

Mixed-integer linear programming models can be used to represent and solve PPM problems (in operations research terms these would be classified as standard 'knapsack' problems). Boolean decision variables represent the decision whether or not to activate a given project, and the objective function generally represents the sum (to be maximised) of the NPV of the selected projects. Constraints are added to ensure that activated projects do not require more resources than those available, and other constraints can model interdependence among projects.

Complex optimisation models following this approach may be found in the papers by Dickinson *et al.* (2001), who include NPV, strategic fit and project interdependence, and by Loch and Kavadias (2002), who use a dynamic programming approach and model risk aversion and interaction among products.

Multi-criteria methods

In the project selection process, projects must be compared according to heterogeneous criteria, such as economic value, risk, coherence with the firm's strategy and competencies, project complexity, *etc*. Some of these criteria are difficult to assess in economic terms, and decision makers are usually reluctant to endorse such a process, since they realise that the results would be rather unreliable. Multi-criteria evaluation techniques, such as *Electre* (Roy, 1996) or the analytical hierarchy process (Saaty, 1980), help compare projects on heterogeneous criteria in a more natural way.

In the project selection process, projects must be compared according to heterogeneous criteria, such as economic value, risk, coherence with the firm's strategy and competencies, project complexity, *etc*.

Despite their potential, these techniques are not widely diffused, partly because of their complexity and partly because managers perceive that they do not have sufficient transparency. This can be a problem when used in a process that, being subject to strong political pressure, should be as clear as possible. Firms, therefore, tend to use very crudely scored models, such as weighted sums with thresholds for screening, as shown in Table 17.14, and tolerate the fact that the attribution of weights and scores is arbitrary and that the final results can often be paradoxical.

Weight	2		3		
Threshold	**	…	***		
Criterion	Criterion 1	…	Criterion n	Passed?	Score
Project 1	***	…	*	r	r
Project 2	***	…	***	a	12
…	…	…	…	…	…
Project m	**	…	****	a	16

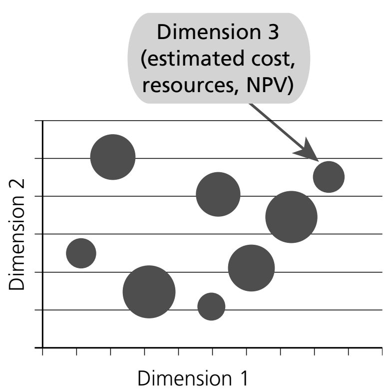
17.14 Using weighted sums with thresholds for screening projects

Mapping methods

PPM also requires tools for visualising, in an intuitive way, the project portfolio and related data. A popular approach is to use bubble diagrams, with two variables expressing 'project positioning' on the Cartesian axis and the bubble size proportional to some measure of project size (Figure 17.15).

The implicit message associated with mapping methods is that the firm should go for a 'balanced' project portfolio, which of course may not be the optimal one. The dimensions that can be used for these bubble diagrams include:

- strategic fit (for example, high, medium, low);
- duration of competitive advantage offered by the project (for example, short, medium and long-term);
- economic value;
- technological level (for example, from standard to breakthrough technology);
- probability of commercial and/or technical success (for example, high, medium, low);
- project complexity (for example, high, medium, low);
- market attractiveness;
- investment required for development;
- investment required for commercial exploitation;
- lead time;
- product innovation.



17.15 'Product positioning' using bubble diagrams

In classifying projects for mapping purposes it may be useful to follow the proposal by Shenhar (2001). On the basis of empirical research, he presents a taxonomy for development projects using the two axes of technological uncertainty and system scope. In addition, he suggests two qualitative but formally defined measurement scales (one per axis), that ensure greater fit with empirical results and, therefore, a less error-prone classification of projects.

Application of project portfolio management techniques

The previous list of techniques shows that firms have many 'building blocks' available to set up a proper PPM process. However, firms exhibit widely different behaviour in their PPM practice. Cooper *et al.* (1999) present a survey of PPM practices in more than 205 firms and find that satisfaction with PPM depends on the quality of the process and to what degree it matches management's requirements. They then find that 'benchmark' businesses (*i.e.* the ones that exhibit a PPM approach with a high degree of quality and management fit) share five main common traits:

1. the PPM methods are established, explicit, formal and with clear rules;
2. the PPM method is applied constantly;
3. the PPM method considers all projects together and pits them one against the other;
4. management follows recommendations from PPM methods;
5. PPM is based on a combination of financial methods and of tools that help evaluate the degree to which projects fit with the firm's strategy.

Conversely, they find that firms using financial methods alone derive the worst satisfaction from PPM. In a subsequent paper Cooper *et al.* (2000) warn against PPM methods that evaluate projects independently from one another and neglect resource absorption, which implies they do not consider the opportunity cost that arises when resources are committed to one project and not to another one. They suggest that PPM should be realised on the three axes of economic value, strategic orientation and balance across markets and scope (*i.e.* short vs. long term).

Defining a balanced project portfolio with respect to project scope is not easy, because of the uncertainty associated with projects in general, and especially long-term ones. In this area, literature proposes simple mapping approaches together with more complex analytical studies. Concerning the former, Mikkola (2001) proposes a mapping-based method in which projects are located depending on competitive advantage (or scope) and benefits to customers.

Defining a balanced project portfolio with respect to project scope is not easy, because of the uncertainty associated with projects in general, and especially long-term ones.

Coskun Samli (1996) proposes a process for developing breakthrough products based on three phases (generating, evaluating and prioritising ideas).

Among more sophisticated papers it is possible to mention Ding and Eliashberg (2002) and Lieb (1998), who both propose analytical models of a two-stage development process with upstream 'research' feeding into downstream 'development' after an intermediate screening. Lieb looks for the optimal 'choke' between the two phases (*i.e.* the fraction of projects that should be allowed from one to the other). The trade-off he studies arises because a tight choke leads to fewer effective projects in the development phase and/or the need to start many more research projects in order to feed development at the required rate. A wide choke means that too many possible failures are taken into the development phase. The elements that determine optimal choke are the relative cost of research vs. development projects, and the firm's ability to discriminate between good and bad projects at the review point. The discussion shows that two elements become of paramount importance: the generation of an adequate number of high-quality concepts in the research phase and a quality project screen.

Conclusions

This chapter has reviewed the topic of product portfolio management, which is of strategic importance to a firm in general and, specifically, to the processes that are tasked with developing products. Because of the breadth of the topic it has been necessary to tackle it from a number of perspectives, starting from the side of marketing. The benefits and the possible drawbacks of a broad product portfolio have been discussed by comparing the basic economics of product differentiation with recent results on product proliferation. The chapter has then covered the 'back end' of product portfolio management. First, modularisation and platforms, which are two mainstays of modern product development strategy, have been introduced and critiqued in order to highlight the trade-offs that determine their applicability. Then, a few contributions on MPM have been reviewed. Finally, the two perspectives have been brought together by introducing PPM as a process that can help determine the product portfolio by simultaneously addressing issues of supply and demand. PPM has been discussed with regard to overall methodology and related support techniques.

Product portfolio management is of strategic importance to a firm in general and, specifically, to the processes that are tasked with developing products.

Despite the hype that clouded the so-called 'new economy' at the beginning of the decade, it is undeniable that most firms nowadays operate in an environment that is more complex than the traditional linear supply chain, in which each company developed a clearly identifiable product and positioned itself between a well-defined set of suppliers and customers.

Corporate 'unbundling' (Hagel and Singer, 1999), the phenomenon in which the three processes of product innovation, customer relationship management and infrastructure management are no longer performed by the same company but demerged in different firms, is indeed happening in many industries. For instance, cellular phones are often designed by the former 'manufacturers' (for example, Samsung, Nokia, Sony-Ericsson and Motorola), produced by Far East contract manufacturers, and sold under the brand of network operators (for example, Vodafone Live!). The same may be said for the ecosystem model (Moore, 1993), in which a number of companies cooperate within a complex and dynamic network of relationships that go beyond the traditional links between suppliers and customers.

So, the natural question is, what happens to product portfolio management when the firm is unbundled, operates in an ecosystem, or provides a product-service? In principle, one might say that two complementary perspectives have been achieved. From the perspective of each unbundled firm, it is necessary to redefine the local concept of 'product' and product portfolio and use traditional techniques in order to manage it. For instance, the 'product innovator' will have to manage a portfolio of product designs, the 'customer relationship manager' will have to manage a set of customised services obtained by assembling physical 'building blocks' with service-oriented processes, while the 'infrastructure manager' will manage a portfolio of manufacturing services. This perspective must be completed with an inclusive picture of the product portfolio that end users are effectively observing and buying (in other words, one must remember that "the whole is greater than the sum of the parts"). This picture should be used to assess the profitability of all the cooperating parties, so as to ensure their commitment.

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