

The Economics of Product Development: A Marginalist/Evolutionary Synthesis

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by

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Abstract

Rival firms produce products with a multitude of characteristics (Lancaster, 1966) and consumers choose to purchase those products that most closely match their ideal set of characteristics. Orthodox production theory ignores the view that products are bundles of characteristics and consequently it offers no analysis of how to divide limited production budgets between different characteristics. It also ignores the heterogeneity of firms with respect to their capabilities (Penrose, 1959, Richardson, 1972) and the fact that production decisions are undertaken in historical time (Nelson & Winter, 1982). Each of these factors has implications for the firm's feasible productive set at any point in time and its production strategy. Here a new framework of analysis of production is offered which incorporates these missing features. In addition it incorporates lessons from behavioural consumer economics (Earl, 1986), which recognises the possibility that consumers may have hierarchical preferences over characteristics, rather than trade-offs between them, and that they will form aspiration levels for each characteristic in terms of actual or perceived performance.

Keywords: production, characteristics, aspiration level, heterogeneity, capabilities, knowledge, learning.

JEL codes: D11, D21, L21, L23, M21

1 Introduction

This paper reworks some familiar tools from orthodox equilibrium economics and integrates them with inputs from evolutionary economics to deal with some issues that emerge as significant once it is accepted that actual economies are evolving in historical (real) time. Orthodox production theory essentially reduces to a problem of choice involving a menu well-known alternative techniques relating input combinations to output levels of given products, subject to particular unit prices for the inputs. The following topics are typically beyond its purview:

- Innovation - the set of products that may be produced is not static (Schumpeter, 1934).
- Knowledge - the accumulation of capital by firms does not take place in the context of a given state of technological knowledge with a pre-specified set of blueprints from which to choose. Rather, firms keep developing new, more productive techniques. Hence, 'The blueprints are drawn when the technique has been chosen, and it will rarely turn out, after the event, that exactly the best possible choice was made' (Robinson, 1975, p. 39).
- Learning - even where no new investment is made in terms of expenditure on capital equipment or spending on training staff, productivity may increase as time passes due to learning effects (Wright, 1936).
- Capabilities - firms differ in what they can do in terms of productivity or the product characteristics they can produce for a particular outlay (Penrose, 1959, Richardson, 1972, Nelson and Winter, 1982).

In particular, orthodox production theory sits uneasily with a capabilities perspective in which specialisation and learning play a central role and give rise to heterogeneous capabilities which heavily influence the costs that firms will incur if they choose to shift from one production technique to another (as well as possibly limiting their ability to make any shift). An issue of major significance is the possibility of non-substitution between capabilities (i.e. production systems that involve prerequisites and co-requisites), especially in markets where, as suggested in heterodox consumer theory, many buyers are using decision rules based on checklists or priority rankings, and competitive pressure is leading to rising standards being required (the 'Red Queen Principle' from evolutionary theory (Van Valen, 1973)). Path dependence is also a key issue: where investment is funded from profit plough-back, cash-strapped firms will tend to get locked into ultimately futile attempts to upgrade by incremental rather

than radical changes in the products they offer. We will attempt to show how production theory looks when it embraces such issues.

2 The shape of consumer preferences

Despite Chamberlin (1933) having made the specification of the product a decision variable in his *Theory of Monopolistic Competition*, and despite forty years passing since Lancaster (1966) used tools from mainstream consumer and production theory to remodel consumer demand in terms of product characteristics, expositions of production theory typically proceed as though the product in question is given. An important exception to this is the work of Grupp and Maital (2001), who try to apply standard microeconomic tools to the task of choosing where a firm might best devote its research and development efforts. In their 'features-based approach to innovation' they focus on the costs and benefits of developing new products (or improving existing products) to comprise one bundle of characteristics rather than another.

The approach taken by Grupp and Maital can be characterised as follows:

1. For each product characteristic, assess how the firm's existing or imagined product performs on a 'technometric' reference scale, its value lying between 0 (the worst performance offered by an existing rival) and 1 (the best performance currently available in this product dimension).
2. Find out the importance that prospective buyers attach to particular features, or their willingness to pay for them, using hedonic price equations or conjoint modelling.
3. Estimate the inputs required to make incremental improvements for each of the characteristics offered by the product and then use programming methods to find the optimal allocation of the resources available for getting the best ultimate design of product in terms of the cost of making improvements and the revenue benefits from making them.

As well as looking at the overall market, with a focus on average ratings of customer's for particular features, Grupp and Maital also show how this line of thinking may be applied to market niches where groups of customers cluster with similar sets of preferences.

The use of the 0,1 technometric scale for each product characteristic is ingenious. It means that Grupp and Maital are able to present visual summaries of the 'profiles' of rival products in just two dimensions even though the products themselves may have a couple of dozen dimensions of interest to customers. Their profile diagrams

use the 0,1 scales as their vertical axes and then line up the average customer ratings of the importance of product characteristics on the 0,1 scale beginning with the highest on the left, followed by the others in decreasing order. This, they suggest, gives the 'customer preference profile' (see Figure 1 below for an example). For each product in the market a technometric profile can also be drawn with its actual performance on each characteristic, measured on a 0,1 scale mapped against the respective importance rating assigned by customers.

The obvious thing for the firm to try to do, costs permitting, is to come up with a product whose technometric profile aligns with or is consistently above the customer preference profile. It is where resources are restricted, as will normally be the case, that the firm will need to make choices about which areas of its product to try to improve, given the resources at its disposal, and this is where Grupp and Maital's cost-benefit/programming approach is intended to help.

From the heterodox standpoint, there are two limitations with Grupp and Maital's extension to mainstream microeconomic analysis. One, which we try to deal with later in this paper, is their tendency to assume linearity in product development processes and hence point in the direction of using linear programming as the means of finding the optimal product development strategy. The other issue is the presumption that customers are always willing to make trade-offs, linear or otherwise. This is at the heart of the demand modelling methods that are used in their work. From the heterodox standpoint (e.g. the perspective of behavioural consumer economics), however, it is possible that many potential buyers will approach the task of choosing by using a checklist that defines a required performance template, or by setting targets for performance levels (i.e. forming aspiration levels (Simon, 1955)) on each characteristic, ranking these characteristics in order of priority and opting for the product which gets as far down this list as possible without failing at least to match the aspiration levels recorded in what we call the 'customer aspiration profile' (see Bettman, 1979; Earl, 1986, 1995).

Figure 1 revisits Grupp and Maital's product profile idea from the checklist/priority standpoint. It shows a hypothetical customer aspiration profile for small cars and how two brands fare against it. Brand A beats brand B on only five of the eleven characteristics shown and is vastly inferior in terms of the fourth-ranked characteristic, safety, where it falls short of the typical customer's aspirations. However, while brand B is in many senses a more rounded performer and meets safety aspirations, it would be beaten by brand A because it falls short of the market's demanding standards in terms of styling, which is ranked above safety at number 2. A suitable appealing restyle of brand B would enable it to beat brand A, unless brand A's safety

rating were improved, in which case brand B's cramped interior lets it down at the seventh hurdle. If brand B were both restyled and repackaged in terms of its interior to meet customers' aspirations, the decisive test would then become that of the quality of finish, where neither presently is up to scratch but where A is the less bad of the two, so A would win.

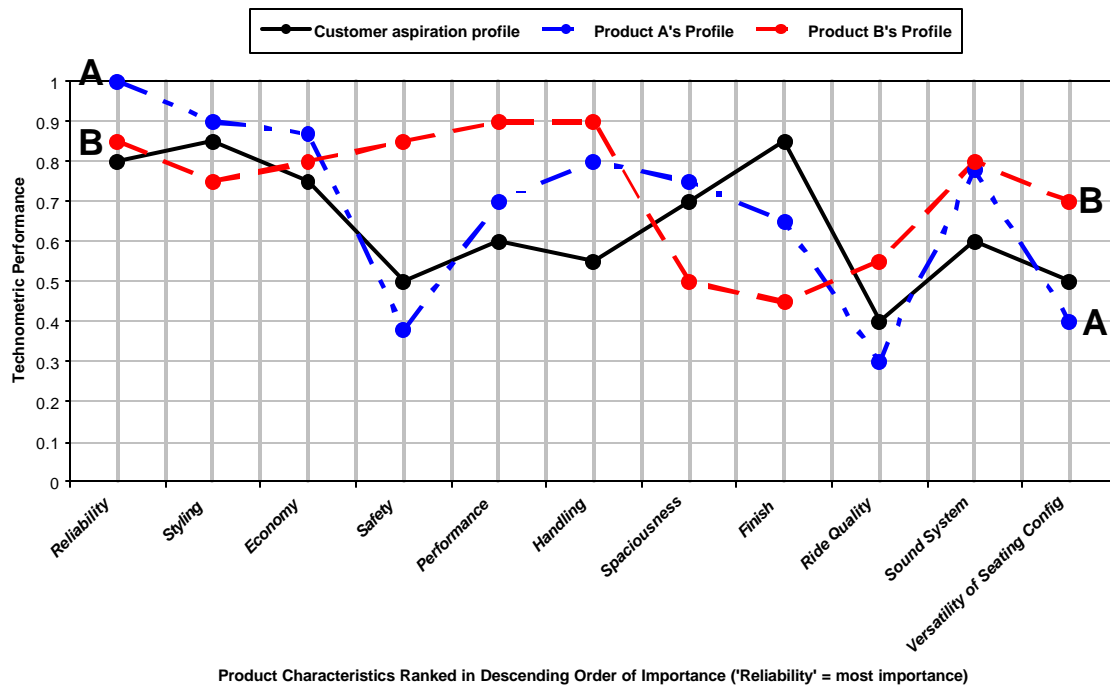


Figure 1. Hypothetical Profiles for Small Cars

In terms of a hierarchical view of preferences, we can see that brand A's manufacturer would be making a serious error if it reacted to a loss of sales caused by improvements in brand B's styling by concentrating on improving its ride quality and finish, and not addressing the safety issue, even if these were areas where market research indicated it was failing to make the grade.

In the diagrams and analysis in the rest of the paper we are not using the technometric scales approach to show product characteristics. Instead, our characteristics axes will begin with the level of performance the firm is currently offering on that dimension (which in some cases might be zero) and then are open-ended, in whatever units the firm might be using to measure its product's

performance in that area. This approach enables us to focus on the expected costs and revenue gains of improved performance in a particular dimension without the analysis being clouded by investments already made to bring the firm to a particular level of performance if that lies between best-practice and worst performance of rivals. It also makes it easier to apply the analysis to cases where the firm in question sets out to offer a better performance on the dimension than has previously been offered. (In terms of a technometric scale, the firm's new product would become '1' on the scale and lower values would have to be assigned to all of its rivals aside from the worst one, which would remain at '0'.)

Grupp and Maital's approach does not direct attention at the possibility of a firm trying to do this, because they presume customer demands will be somewhat less than the existing best practice. However, it is by no means uncommon for firms to set out to 'rewrite the rules of the game' and 'provide a new benchmark' for products in their class by demonstrating to potential customers that they can demand more than they have been used to without making sacrifices on other dimensions in order to get it. A case in point is the 1983 Audi 100, whose use of devices such as flush glazing to engineer a spectacular increase in large-car fuel economy was widely copied. Not only could buyers now realistically hope to achieve an average fuel consumption figure of at least 30mpg, but for a time, firms started competing, in their advertising, in terms of a possible new decision criterion, namely whether a car (like the Audi) had a drag coefficient of 0.3 or less.

Before moving on, it is important to add that the question of how to measure performance in a particular dimension is often far from straightforward. In the case of car safety, for example, it is important to know whether customers are setting their aspiration levels in terms of, say, laboratory scores achieved in crash testing programmes such as EuroNCAP, or more likely, in terms of published summary star-ratings or in terms of the number of airbags, or in terms of rating systems based on actual accident outcomes. Such systems may produce quite different rankings of rival products and have very different implications in terms of the costs of re-engineering one's product to meet them—for example, it will be far cheaper to add side airbags than re-engineer the body structure so that it can better withstand a side impact.

3 Revenue profiles for improvements in characteristics

Given the mix of decision rules that potential customers are using, there will be a separate demand function for each combination of characteristics that the firm may offer. However, we can also imagine

the firm looking at the revenue it may get by increasing how much of a characteristic it offers whilst keeping the other characteristics constant. With a given price and given other characteristics, the firm will have conjectures about the impact of changes in a characteristic on its sales volume and hence on its revenue. Clearly, we can draw graphs of these ceteris paribus characteristic improvement/revenue improvement relationships. However, if we are trying to understand the maximum it would be worth spending on improving performance on a characteristic, what we really need to graph is the relationship between the change in a characteristic and the maximum increase in net revenue that it is possible to generate for each possible level of the characteristic over the time horizon in question (such as the expected life-cycle of that variant of the product). In this instance, what we mean by 'maximum net revenue' is the outcome of calculating the optimal combination of increase in price and increase in quantity less the increase in total (variable) costs of offering more units of the product in ceteris paribus terms.

To make this point clearer see the example in Figure 2. Imagine a carmaker in the early 1990s, considering whether to add a driver's airbag to one of its products. From its market research, the firm will have an idea of how much the demand curve for its product will shift to the right in going from zero to one airbag without changing any of its other features. It should also be able to estimate the marginal cost of supplying extra cars without any airbags. From orthodox pricing analysis in terms of $MC=MR$, there will be a price that maximises profits *as if the airbags had been included at zero cost to the firm*. The increase in net revenue compared with the no-airbag case is then the maximum amount that the firm could spend on adding the airbag to the *total* number of vehicles sold without it reducing its profits. For example, suppose the relevant figures are: optimal price without airbag \$20,000 and sales quantity 230,000 units; price with an airbag \$20,750 and sales quantity 235,000 units. If the unit costs per vehicle without an airbag are \$15,250,¹ then the impact on net revenue is $(\$20,750 \times 235,000) - (\$20,000 \times 230,000) - (\$15,250 \times 5,000) = \$200\text{m}$, i.e. \$851.06 per car sold. It can go through the same thought experiment in terms of adding both driver and passenger airbags, and, yet again, side airbags and so on, with each addition moving the car's demand curve further to the right.

The set of results from such thought experiments comprises what we call the 'revenue gain envelope' for this characteristic. It is what the firm will need to focus on when deciding on the specification to try to offer for the product. Figure 3 contrasts orthodox and

¹ We have assumed constant unit costs in figure 2 to simplify the analysis.

heterodox perspectives on the likely shape of the relationship between improvements in performance and improvements in revenue. Revenue is shown on the vertical axis and the horizontal axis represents the level of the characteristic being offered. This analysis is presented on the assumption of a particular set of performance levels on all the other characteristics. We consider later in the paper the economics of juggling the mix of two characteristics.

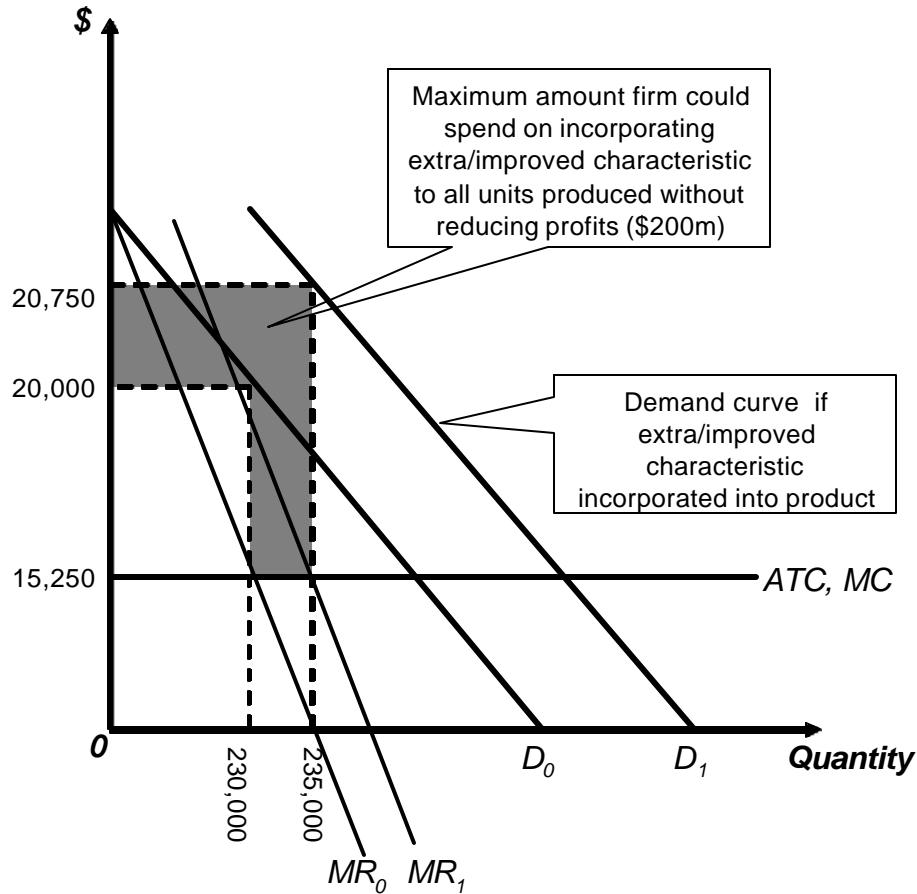


Figure 2. Calculating the maximum amount to spend on improving/adding a single given characteristic *ceteris paribus*

In terms of conventional thinking, the kind of revenue improvement envelope that we should expect managers to envisage is a line that begins at the bottom-left and rises to the right, either as a sloping straight line (implied via a standard linear hedonic regression model), or with a decreasing slope (implied by a diminishing marginal utility/rate of substitution between this characteristic and others). However, if the market (whether as a whole or in particular segments)

is populated mainly by customers who are setting targets and are unwilling to settle for less, and if these customers are setting similar targets, this will produce revenue profiles for product characteristics very different from what the orthodox analysis would lead us to expect. From the heterodox standpoint, what we should expect is an S-shaped curve. A little of the characteristic attracts virtually no extra customers compared with not offering the feature at all. Adding more of the characteristic wins a few extra sales, from customers who are choosing in the orthodox manner, but when the commonly-demanded target level of performance is offered, sales and revenue sky-rocket. Further increases in performance on this dimension may also increase revenue, both from customers doing trade-offs and from customers with heterodox preferences who use dominant performance on this characteristics as a tie-breaker, or who are prepared to make trade-offs between characteristics once they are in their target area for all 'must-have' features.

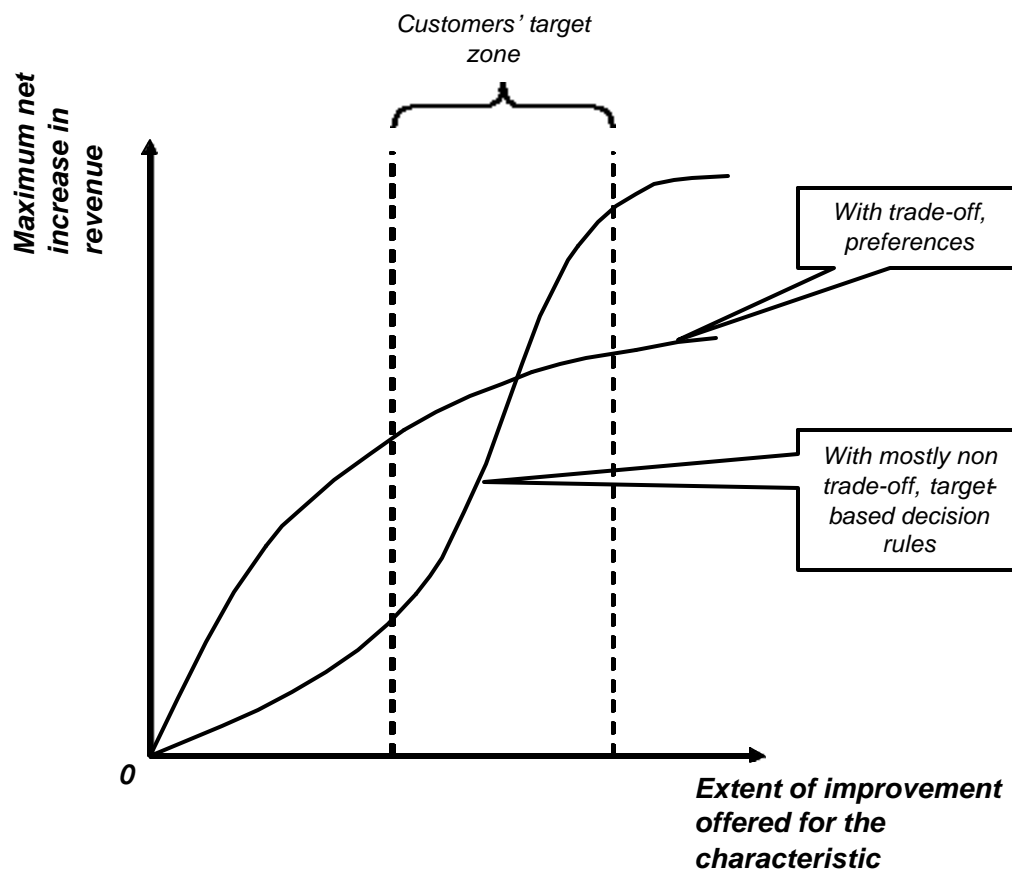


Figure 3. Revenue impacts of changes in the amount of a characteristic offered

With these S-shaped characteristic-revenue curves, the height of the 'sky-rocket' middle section will depend on the ranking of the characteristic. If many consumers rank it first in priority, or it is one of a 'core' checklist group, then if the product performs adequately in the other dimensions, meeting the target figure on this dimension may be all that is needed to unleash a flood of demand, but without this most customers will reject it. With lower priority characteristics, the revenue impact of coming up to the target will be rather limited unless a shortfall means the product is one characteristic behind some of its rivals in terms of the number of hurdles it gets over. Reaching the target may give it a chance at a tie-break or may enable it to win because it fills a gap in the list of tests the product can pass and buyers who choose it can go on to meet targets further down the list that they cannot meet if they choose a rival brand.

It is important to recognize that these revenue curves will move to the right as time passes. This is because the average performance of each characteristic will tend to improve and with it the aspiration level that customers set. For example, in the late 1990s, dual airbags might increasingly have been the aspiration level on a car, whereas nowadays not having six may well be frowned upon by a large part of the potential market.

4 Capabilities and product development costs

We now explore the costs that the firm's managers may consider as they investigate how far to go in improving the performance of their products. In the short run, when the management team cannot change some of the resources at their disposal, attempts to increase the output of particular product characteristics may run into steeply diminishing returns, or even hit a performance ceiling. In terms of the capabilities approach to the firm, the problem here typically is not merely that some of the assets the team is currently stuck with are specific to other uses but that they do not have access to resources capable of performing functions needed to get the product's performance up to the next level and beyond (so they face *dynamic transaction costs* which are 'the costs of not having the capabilities you need when you need them' (Langlois and Robertson, 1995, p.35)). Specific capabilities may be required to solve particular product development problems—in much the same way as particular sets of 'A-level' grades are prerequisites for entering particular universities and degree programmes. Even if a management team spends heavily on buying talented staff it may still fail to hire those who know what members of their better-performing rivals' teams already know. Knowledge may be embedded in particular individuals who are unable

or unwilling to join the firm or it may be to some degree tacit in nature (see Polanyi, 1962, 1967) and difficult to transmit to other members of a product development team.

For each characteristic, the managers may be in a position to estimate the costs of achieving particular levels of performance within a target time period (such as by the time they launch their next generation model two years from now). These costs comprise:

1. Fixed costs of research and development;
2. Fixed costs of tooling up to incorporate the performance improvement;
3. The sum of variable costs that would need to be incurred at the revenue-maximising sales level the firm expected to achieve if this product specification were offered.

In terms of our airbag example from the previous section, the numbers might stack up as follows. Estimates for the development cost might be, say, \$25m, the tooling costs \$10m and the total variable costs, at \$250 extra per car would be ($\$250 \times 235,000 = \58.75m), a total of \$93.75m, so it would be worth going ahead given that the total expected net revenue gain without including the cost of the airbags is \$200m.

We must make two qualifications before going further. First, in terms of the orthodox $MC=MR$ approach to pricing, there is clearly a slight contradiction in what we have been saying. The optimal price for a particular level of the characteristic is calculated with no allowance for the yet-to-be-discovered marginal cost of including it on each unit sold. Clearly, there will be an addition to variable costs and this will imply a higher price and smaller quantity if profits are to be maximized in terms of orthodox analysis. Once the firm has got a clear idea of the variable cost implication of making the particular performance upgrade, it could perform such calculations and change its intended price. However, from both a contestability perspective and a heterodox perspective focused on mark-up pricing, such greedy pricing may not be wise: if the improvement looks like it will be very profitable others are likely to copy it (or be working on it already!). From the latter standpoint, a further pricing iteration might thus be in the direction of a *lower* price, to make things tougher for rivals who do not offer this level of performance, not a higher one whose benefits would be very short-term. We recognize that either kind of iteration might make sense but we wish to emphasize that the approach taken here is offered primarily as a way through which managers can organize their thoughts about where and how far to improve their products. *It is a*

means of coming up with budgets within which engineers can be required to work.

Secondly, heterodox economists might well be somewhat uncomfortable with the idea of managers being able to come up with estimates of the costs and revenues of taking the firm into new territory. For one thing, the development costs and the variable costs of incorporating the improvement may be interdependent: if more is spent at the development phase, a simpler design with fewer parts might be possible. With path-breaking changes involving research and development over a decade or more, such as the first digital cameras, the investments would probably be very much a leap in the dark, not least of all because it would be unclear who would be 'first to market' with a finished product, when that would be, and to what standard of performance. However, much that is new in the market is actually little more than new combinations of existing technologies (see Earl, 2003), re-engineering of someone else's product, or incremental improvements. Engineers therefore ought to be able to form conjectures, at least of best-case and worst-case scenarios, based on precedents.

For simplicity and clarity in the graphs that follow, we focus on single-line estimates rather than showing bands to represent the range between best and worst-case scenarios. Furthermore, we depict curves showing the costs of developing products and producing them to incorporate particular characteristic levels as if they have quadratic, exponential or logarithmic functions to reflect the diminishing returns to what the firm can do with its existing resources, and the ultimate limit within the time horizon in question. However, we suspect that in reality, these functions may tend to have a reverse-S-shape, implying that up to a point the incremental cost of improving performance on a characteristic falls due to learning effects and only after this point does it get harder and harder to eke out more performance. In the case of airbags for cars, for example, there were major set-up costs to figuring out and tooling up for the driver's steering wheel airbag's sensors and hardware, but much of this could be incorporated into the passenger's airbag and seat-mounted side airbags. By contrast, whilst side curtain airbags could use much of the same technology, they were often much tougher to incorporate unless part of a major model re-design programme that allowed a different roofline.

In Figure 4, we plot the firm's conjectured cost function for improving its characteristic performance on the same diagram as the 'revenue improvement function' for this characteristic. An optimal characteristic level to achieve can be seen readily in Figure 4. This is the level at which the slope of the (increasingly upward sloping) cost function is the same as the slope of the revenue function. This is at

point m with the orthodox revenue function and point n with the heterodox, S-shaped function. If the characteristic's revenue function is S-shaped with the 'sky-rocket' part of the S only sloping slightly to the right, and if the firm finds it something of a struggle to get much beyond the range within which revenue sky-rockets, then the optimal position will tend to be close to the level at which the upper inflexion point occurs. Clearly, if we had drawn the cost functions as reverse-S-shaped, multiple solutions would be implied in first order optimisation against an S-shaped revenue gain function. The solution for the lower value of the characteristic would tell us the least profitable level of the characteristic to offer.

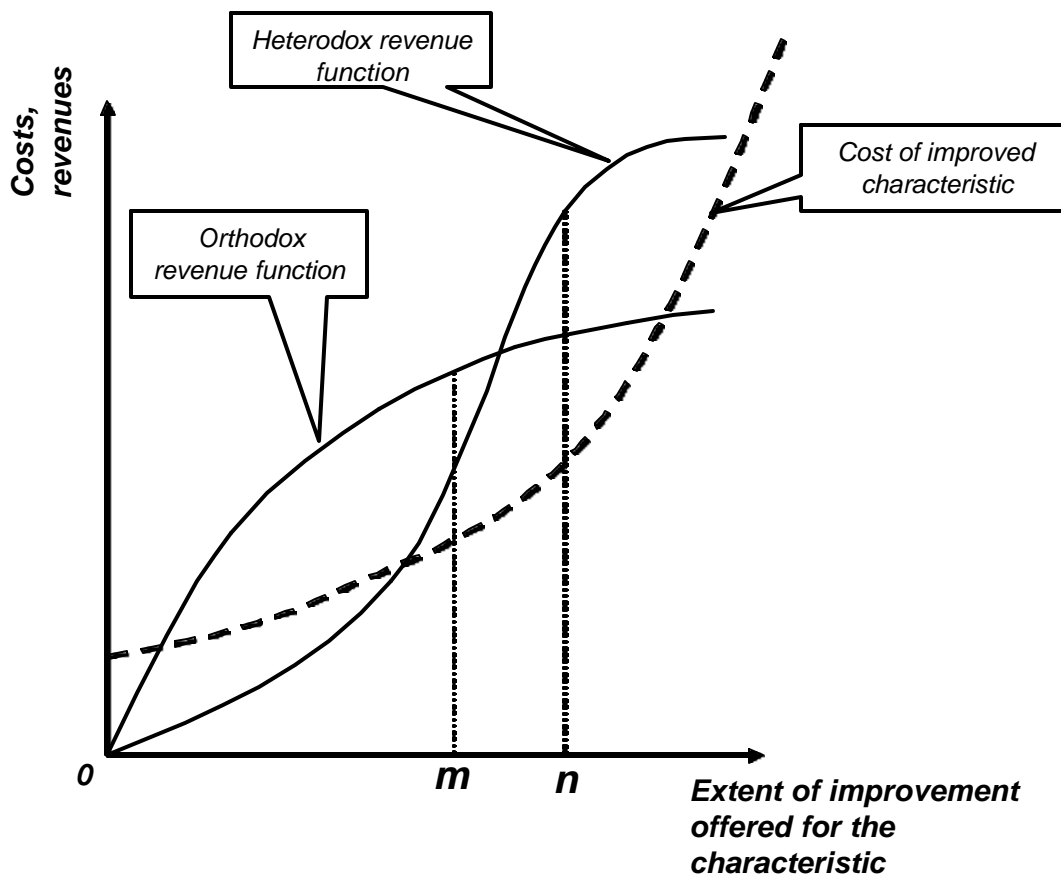


Figure 4. Costs and revenues for improving a single characteristic

The costs of investing in improving performance may seem very small compared with revenues in the case of high priority characteristics in a case where the heterodox view applies. This is

because using the resources to improve performance on lower priority features would have virtually no beneficial impact on revenue as potential buyers are rejecting the product due to its shortcomings on the higher priority characteristic. The investment rule would in essence be to allocate resources to improving product characteristics in terms of a priority list based upon the ranking of areas of inadequate performance. Thus if aspiration levels for priorities 1 and 3 are being met but those for 2 and 4 are not, then characteristic 2 has first claim on resources up to the point at which it is being met and what is left over should be assigned to 4 and only if any resources are left over after enough have been earmarked to sort out that problem area should any be made available for work on lower priority characteristics. (See also the discussion earlier regarding brands A and B in Figure 1.)

5 Capital budgeting between rival characteristics

The analysis in the previous section is essentially a partial treatment that we might think of a firm as applying separately to each characteristic in its product's profile to work out the best product to offer within the time horizon to which it was working. It is possible to focus on one characteristic at a time so long as two conditions hold.

The first is that there are no externalities between the characteristics in terms of how they relate to consumer preferences/decision rules, i.e., the product is seen simply as the sum of its parts without any emergent properties that depend on the parts being combined in particular ways. In the case of a car, for example, an emergent property might be its perceived 'sportiness', which might be affected jointly by the quality of its styling, the wheels fitted to it, its power/weight ratio, its height, and so on, in ways that were not simply additive. (For example, body styling that seems svelte when combined with upmarket alloys, fat tyres and lowered suspension might look somewhat ridiculous with skinny tyres on steel wheels and a conventional ground clearance.)

The second condition is that there is no financial constraint to prevent the firm from financing all of the product improvements that it deems profitable. In reality, even though an improvement looks like it will pay for itself if undertaken, the firm may simply not have the resources to go ahead with it at the moment. The issue here is not particularly a matter of the analysis in Figure 4 being rather cavalier in its treatment of time—it could be made more sophisticated by allowing for the discounting of the stream of enhanced revenues that comes after the money has been spent on upgrading the product. Rather, the problem lies with imperfections of capital markets that result in many firms seeking to finance their investments from ploughed-back profits.

Some heterodox economists such as Eichner (1976/1980) have made the relationship between profits and investment central to their work. However, the picture they offer tends to be of firms having market power that they can choose to exploit today, to gain extra profits to do the investment they would like to undertake, but only at the cost of their fat profits attracting in more competitors and thereby reducing their market power. On this kind of analysis, there may be some kind of steady-state profit rate/investment relationship in which the investment keeps giving them enough of an advantage to keep their market power intact. This perspective might describe well what happens in some markets but the frequency of reports in the financial press about firms having developed the best that they could do given the funding they had is something that we take as implying a rather different situation. It is a situation more in line with Downie's (1958) analysis of the competitive process in terms of a tension between the tendency for firms with greater market share to gobble up the market share of smaller rivals unless the latter could come up with clever enough innovations or ways of reducing their costs to restore their increasingly squeezed profit margins. (Somewhere between Eichner and Downie lies the heterodox contribution of Wood, 1975.) We might put it more simply, in terms that Kaldor tended use in his economic theory lectures in Cambridge, namely, that the dominant firm in the market is a price leader that can set its prices both high enough to generate the investment funds it requires and low enough to prevent its rivals from getting enough profits to do the investment they would like to do. (For example, consider Toyota's position relative to, say, Mitsubishi in the car market.) The latter, in consequence, end up with products that are relatively under-developed in certain areas and suffer accordingly in terms of the price and market share they can command. Short of the 'fear of being hanged concentrating their minds wonderfully' and producing suitable rightward shifts in some of their characteristic development cost function, the latter will face some hard capital budgeting choices between improvements to rival product characteristics.

This section therefore shows how the budgeting of resources between improvements to different product characteristics can be explored in graphical terms. In Figure 5, the two axes on the top right-hand panel refer to the performance levels of two characteristics, A and B and the concave lines show what performance levels are expected to be achievable if particular amounts are spent. We call these lines 'iso-development cost curves'. They could be constructed purely in respect of expected fixed costs of research, development and tooling required to bring performance to a particular level on the characteristic in question, or they could also be thought of as including

the expected variable costs of building this performance into the volume of products that are expected to be sold at the price that it is optimal to charge when this performance level is offered. Given how we have presented the notion of a revenue gain envelope, it is the latter view of development costs that we have in mind here.

For example, the firm might spend \$20m improving the performance of its product on A and get to level A' , or spend this sum on B and get to B' . Alternatively, if spending \$20m, it might spend \$15m on A and get to A'' and \$5m on B and reach B'' (in other words, to point T on the \$20m iso-development cost curve), and so on. For given increments in dollars spent, the iso-development cost curves get closer as one moves to the right, due to the diminishing returns to spending on improvements within the limitations of the firm's current pool of resources.

The iso-development costs curves bow away from the origins, as in a typical production possibility frontier, because of diminishing marginal rates of transformation between the different applications of the resources. In the iso-development cost curves drawn in Figure 5, we are assuming no externality effects between developing performances on the two characteristics. In reality, of course, this might not be the case. For example, a carmaker might find that its attempts to improve its vehicle's handling interfere with ride quality, while safety improvements add weight and harm fuel economy. In other areas, there might be synergistic relationships between improvements to characteristics: for example, heavier doors on a car might come about due to improving side-impact crash safety but could also do wonders for perceived quality of the vehicle. In the former kind of case, the iso-development cost lines are less bowed away from the origin, and in the latter case, more so.

If customer preferences were all of the heterodox kind, with identical non-negotiable targets for both A and B we could show these requirements by a pair of, respectively, vertical and horizontal lines. The top right-hand quadrant from the point of their intersection shows the set of alternative costings for meeting/over-fulfilling both targets, and the iso-development cost line that just touches the point of intersection of the target A and target B lines shows the cheapest cost of meeting both targets. In the case shown in Figure 5, the firm needs to spend \$15m on development to meet both targets at point U , which involves spending about \$6m in improving the performance on A and about \$9m on improving the performance on B. If the firm had only \$10m at its disposal, it would be unable to meet both targets and would then need to budget depending on which of the targets the potential customers ranked highest. If A were ranked above B, then the least-bad position would be at point V , which meets target A but

falls short of target B. If target B were ranked higher than A, point *W* would be the least bad allocation, meeting B but falling short of A.

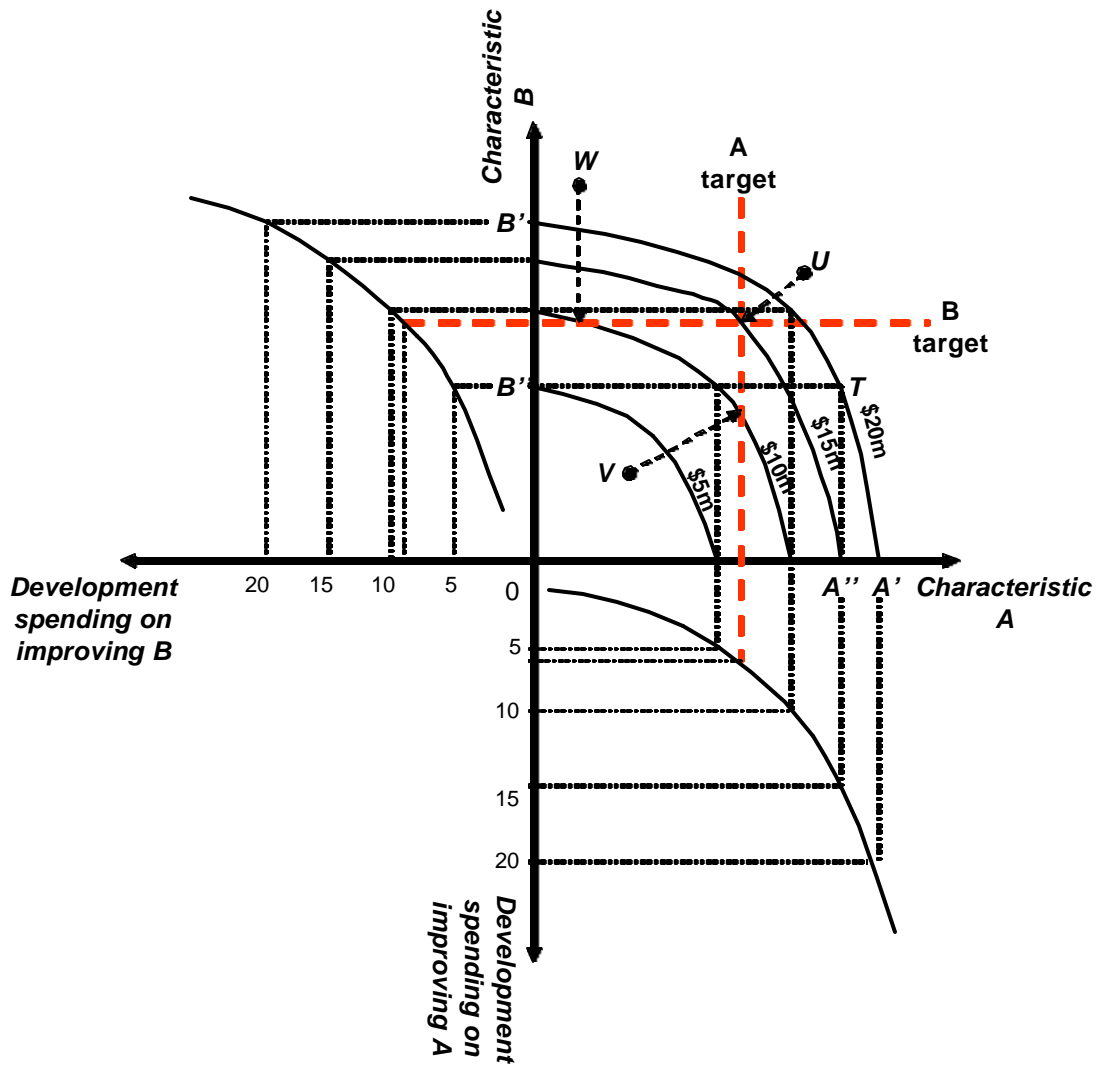


Figure 5. Iso-development cost lines

Where customer preferences involve a mixture of targets for each characteristic, or some consumers making trade-offs and others choosing in a non-compensatory manner, we can graph a set of iso-revenue gain lines for a pair of characteristics. This is done in Figure 6, where the top right-hand panel shows the lines implied by the revenue gain envelopes for two characteristics, A and B. We have chosen to show a case where characteristic A's revenue gain envelope is S-shaped, in line with the heterodox perspective. Combined with a more 'orthodox' kind of envelope for characteristic B, this produces

reverse-S-shaped iso-revenue gain curves. If both envelopes were like the one shown for B, the iso-revenue gain curves will be convex to the origin. However, unlike indifference curves between characteristics, each iso-revenue gain line will intersect with both axes. Take the \$50m line, for example: at the point where it intersects the A axis (at G on Figure 6), it shows that by offering G of characteristic A and none of B, then this adds \$50m to revenue. By contrast, by offering H of B and no A, then the firm would be no worse off in revenue terms: it would be \$50m better off in revenue than if it offered none of both A and B, as indeed it would be if it offered a combination somewhere along this line, such as K.

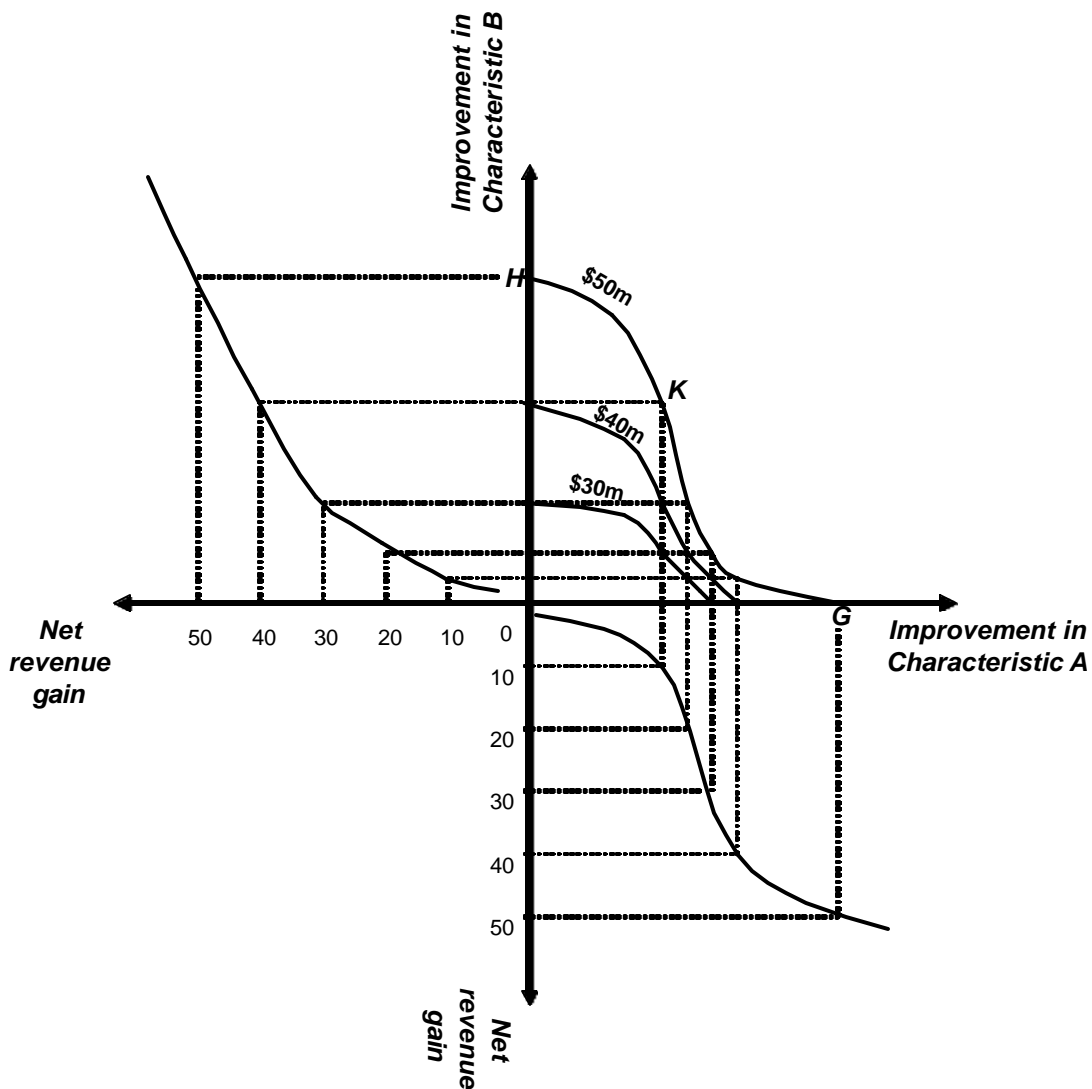


Figure 6. Iso-revenue gain curves

If we superimpose the iso-development cost lines for a pair of characteristics on their respective iso-revenue gain lines, we can readily see an optimal product development pathway being traced by the set of tangencies between the iso-cost and iso-revenue lines. Figure 7 provides an example of this. If the firm has only \$20m to spend on upgrading its product, then the best allocation is at *L*, where the mix of characteristic improvements is expected to generate \$30m extra revenue, a gain in profit of \$10m. Note that if the \$20m were spent only on improving performance on characteristic A, then this would only be expected to add \$15m to revenue (see point *M*). By contrast, if the firm had only \$10m to spend, it might still get \$15m extra revenue and add \$5m to profits by selecting point *N*. Compared with spending \$20m at point *L*, spending \$30m at point *P* is expected to increase profit by \$20m, and spending \$40m is expected to result in an extra \$30m if the firm has that much to spend. If we know what the firm's total development budget is, and how its total investment in the product can grow through time, we can see what it ought to be aiming to achieve as a product development trajectory as time passes (aside from complications cause by rising customer expectations leading to reduced willingness to pay for given levels of characteristic performances). As some stage, moving further along the set of tangencies that define the product development trajectory will cease to add to profits. If the firm has enough resources to get that far then it is in effect back in the situation shown in Figure 4 for each characteristic.

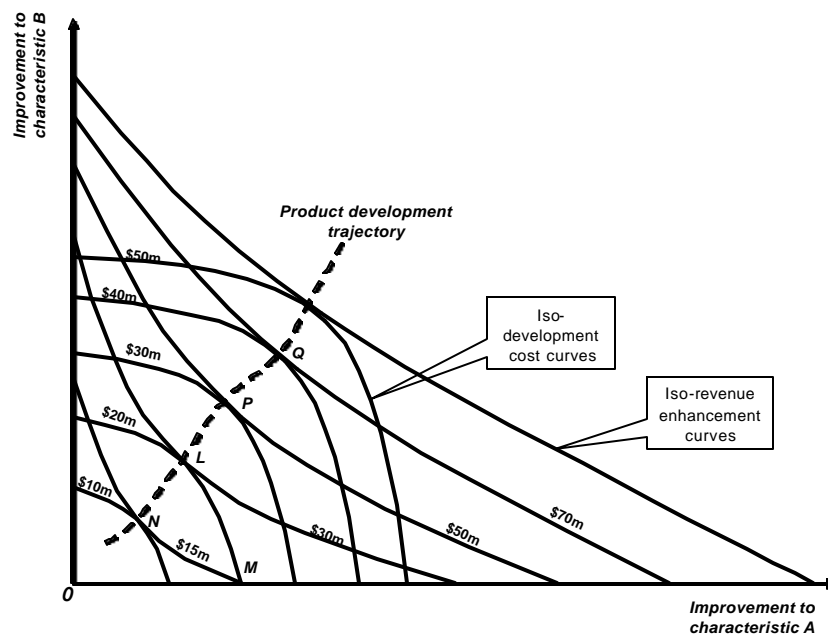


Figure 7. A firm's product development trajectory

Some further observations are worth making at this point. First, it is important to remember that the iso-product development curves are not based on a given production function available to all firms. Rather, each firm will have its own set of curves, depending on how it sees its capabilities and one firm may expect to need to spend much more than another to get to a particular level of performance on a particular characteristic. With preferences that are predominantly as envisaged in orthodox theory, firms could end up following quite different product development trajectories. However, if the market is characterised essentially by preferences of the heterodox kind and customers are thinking in terms of a standard checklist/priority ranking, then firms may need to engage in mergers or strategic alliances to short-circuit the process of acquiring the required set of capabilities to produce the required mix of characteristics.

Secondly, although this framework has been constructed to assist thinking about how firms choose the improvements they make to a single product, it can readily be adapted to apply to the problem of budgeting resources between rival products in the firm's product range when the financial constraint is binding. In terms of a diagrammatic exposition for budgeting resources between two products, we would have axes that represent the amount spent on improving product A and the amount spent on improving product B. A family of iso-product development lines would then be drawn; these lines would be straight and sloping to the left from the horizontal axis with a 45-degree angle. The iso-revenue gain curves would be based on information contained in the two products' respective product development trajectories (remember, these show the set of dominant combinations of product development spending and revenue gain). There will be a set of tangencies between the iso-revenue gain curves and the iso-development cost curves, and the firm's development path for the two products should move upwards to the right along the line defined by the locus of these points of tangency. Economies of scope/synergy between the rival products would cause the iso-revenue gain lines to bow towards the origin.

Thirdly, it is important to reflect on the relationship between the analysis offered here and Neil Kay's (1979) book *The Innovating Firm*, which attempted to provide a behavioural theory of where development budgets come from and how they get allocated. The way in which we have presented our analysis at first sight is opposed to Kay's approach, since he argues against reductionist 'bottom-up' views of resource allocation and in favour of a 'top-down' hierarchical view in which there is a hierarchy of resource allocating decisions within the firm, with budgets being broken down into progressively more detailed constructs as funds are allocated further and further down the

organizational hierarchy. Kay sees the firm as operating like this as a means of dealing with bounded rationality, for it would be a managerial nightmare to try to compare the payoffs of alternative allocation bundles that comprised vast sets of highly detailed projects and clearly firms do not operate like that in practice. His formal analysis, like ours, actually makes use of mainstream methods of modelling managers' preferences. However, his is more redolent of the 'utility' tree model of separable preference functions proposed by Strotz (1957). (Strotz adapts the orthodox model of choice to present shoppers as allocating money between broad spending sectors, such as food, clothing and so on, and then allocating those budgets separately, for example, budgeting food successively between meat and vegetables, and between different kinds of vegetables, etc.)

Clearly, with a focus on finding the mix of improvements to individual product characteristics on particular products, our analysis may appear highly reductionist and 'bottom-up'. However, we see our approach as entirely complementary with Kay's and suggest that in practice what is likely to be happening is a kind of 'looking both ways' (Janus-faced) up *and* down process of the kind explored in the work of Kostler (1978) on complex systems. Our analysis is really about the kinds of thinking that will result in competing claims for resources flowing upwards in firms from those who would like to carry out particular projects, for example, between suspension engineers in a car firm and those who work on engines. Higher up in the engineering division, senior engineers will have to decide on how to allocate funds for the development of engines and suspension systems within and between different models in the firm's product range in the light of lower-level engineers' information about what can be achieved, and what the marketing staff are saying about the revenue impacts of making particular kinds of improvements. However, the budget that comes down to the engineering managers will reflect the outcome of higher-level resource allocation that chooses between giving money to engineering products for launch soon, versus marketing, versus 'blue sky' research on technologies with only vague revenue implications way into the future. It is the latter that Kay's analysis covers. Once again, there is a link to Chamberlin's work: we are primarily focusing on the product being seen as a variable, but money spent on engineering might instead be spent on marketing or distribution.

Summing up so far, we have shown how rather familiar sounding notions of iso-cost and iso-revenue lines can be used to analyse the selection of what type of product to develop as a bundle of characteristics. Conventional marginal equalities are also implied if the functions are continuous, but the analysis is perfectly tractable with non-trade-off kinds of preferences. Firms with different short-run pools

of capabilities would have different patterns of iso-cost lines and tend to follow different product development trajectories.

6 Incremental versus revolutionary technological change

In the long run, the firm is not merely able to augment its pool of human and capital resource and learn how to achieve improvements in product volume and performance with a given technology genre; it can also acquire resources and knowledge that enable it to make progress in terms of a different technology. The analysis of how a firm chooses between technological pathways is basically similar to that where the firm shifts from one generation of product design to another, that involves an upfront cost to get to where it had got already using a different set of resources/technology, but lower marginal cost of enhancing performance thereafter.

Within a dynamic analysis of production, the notion of diminishing returns has potential for being recast to relate not to diminishing returns to a fixed factor of production but to diminishing returns to trying to improve performance standards of an existing design of product or production system, keeping core features unchanged rather than by investing in a new generation of products that have, in some sense, a different core. To illustrate what we mean here, consider the case of a carmaker that is trying to extract more performance and economy from its engines. Methods of increasing engine performance incrementally have included the following, and some firms, over a decade or more will have applied a good many of them to an evolving engine design:

- Rework inlet/exhaust manifolds to improve breathing
- Increase number of crankshaft bearings
- Increase number of cylinders (e.g. 2.0litre 4 cylinder to 2.5litre 5 cylinder, or 3.0litre V6 to 4.0litre V8)
- Electric cooling fan to replace belt-drive fan
- Add contra-rotating balance shafts
- Electronic ignition
- Add electronic fuel injection and engine management
- Change cylinder bore in existing block or change piston stroke.
- Change compression ratio
- Replace iron cylinder head with alloy head
- Twin camshaft cylinder head
- Go from 2 to 3, 4 or 5 valves per cylinder
- Add turbocharger (+ intercooler) or supercharger
- Variable valve timing
- 'Drive by wire' throttle
- 'Displacement on demand' for large capacity V8 engines

Note that these are essentially modular improvements that are normally not without precedent and so are capable of being reverse-engineered. Whilst capability requirements may be new (e.g. electronics), the development work may be outsourced to specialists

As examples of non-incremental changes to engine design that a carmaker might undertake, consider the following:

- The firm's first 'own' in-house engine
- From pushrod to overhead camshaft valve actuation
- From in-line to V-block or boxer cylinder arrangement
- Petrol/electric hybrid
- Diesel
- From iron block to all-new alloy block
- To rotary

There may be precedent elsewhere within the firm's product range, or scope to reduce risks by reverse-engineering someone else's efforts. Although the change may be radical in terms of tooling, design elements may be outsourced (e.g. both Ford and Toyota have used Yamaha's input on some of their high performance engines).

A firm that is short of cash may, in the short run, be able to meet (some) performance goals by making piecemeal changes. Diminishing returns may set in as attempts to reach higher performance or economy standards are made, so a piecemeal upgrade strategy ultimately will prove more expensive. Costs of switching between different generations will be increased insofar as performance improvements/cost reductions with the older generation of technology were achieved by making investments in both staff training and equipment that were specific to that technology rather than via more ingenious use of general purpose machinery and tooling. A cautionary tale in this respect is the case of Ford and the Model-T: changing to the Model A involved closing the entire production line for eighteen months, with 15,000 machine tools being replaced and a further 25,000 totally rebuilt (see Selznick, 1957, p. 110). Many of the case studies in Clayton Christensen's (1997) bestseller *The Innovator's Dilemma* are also consistent with the thinking explored in this section.

Figure 8 gives a flavour of this issue in graphical terms, but to make the analysis more pointed we now offer a simple numerical example. We use three simple quadratic equations to explore the problem of making the best choice of time to switch between technology generations. In each case y refers to the cost of achieving a particular performance standard x on the characteristic in question. Generation I is common knowledge (hence the lack of a constant) at

the start but runs into sharply diminishing returns. The other two generations involve an upfront investment to develop a new technology but can eventually be taken to higher performance levels for much lower cost.

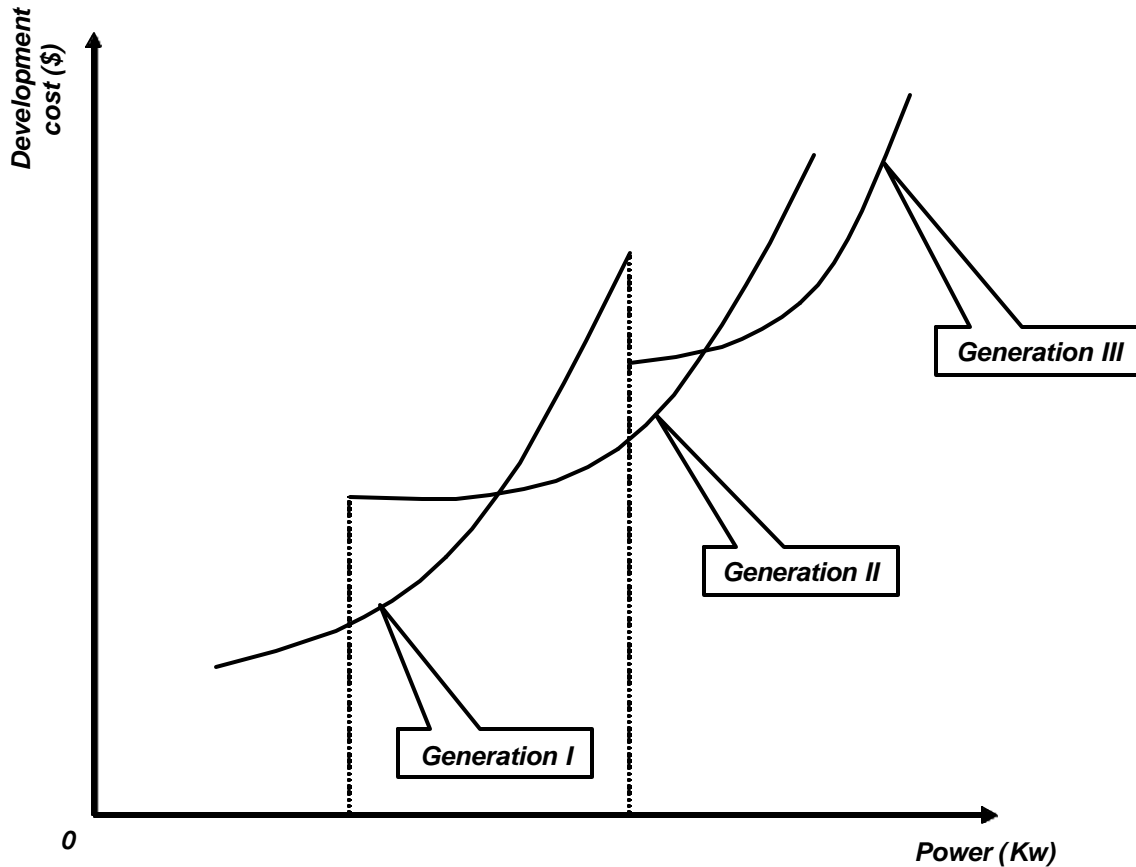


Figure 8. Costs of improving performance under incremental & revolutionary changes in technology.

X	Generation I $y = 10x^2$	Generation II $y = 50 + 12(0.8x)^2$	Generation III $y = 150 + 11(0.7x)^2$
1	10	57.68	155.39
2	40	80.72	171.56
3	90	119.12	198.51
4	160	172.88	236.24
5	250	242.00	284.75
6	360	326.48	344.04

7	490	426.32	414.11
8	640	541.52	494.96
9	810	672.38	586.59
10	1000	818.00	689.00
11	1210	979.28	802.19
12	1440	1155.92	926.15
13	1690	1347.92	1060.91
14	1960	1555.28	1206.44
15	2250	1778.00	1362.75

Now suppose firms A and B have both invested in Generation I technology and have both carried on developing it as far as $X=3$. If firm B then decides to switch to Generation II to get its performance up to $X=4$ and beyond, its total cost at 4 will be higher than A ($90+172.88=262.88$). However, so long as it can keep working at developing the Generation II technology and shoulder any cost disadvantage whilst matching A in terms of performance, by the time they both reach $X=8$ its total expenditure on getting to this stage will now be less than Firm A (631.52, rather than 640). Clearly, if Firm A switches to Generation II at this stage its shareholders will never earn as much as those of Firm B. However, if Firm A switches to Generation III technology for $x=9$ onwards it can reduce its shareholders' relative disadvantage. By $x=15$, Firm A's development expenditure is ($640+1362.75=2002.75$). Firm B, having switched earlier but only to Generation II has incurred development costs of only $90+1778=1868$).

By switching to the Generation III technology and skipping the intermediate generation, Firm A is only spending 134.75 more than Firm B. If Firm A had persisted with Generation I technology it would still have been able to reach $X=15$ but its costs would have exceeded B's by 382. To get ahead of B by $X=15$, Firm A would have needed to make the jump to Generation III technology after reaching $X=7$ at the latest, i.e. *whilst Firm B's accumulated development costs were still running ahead of its own*. At $X=8$, with the switch to Generation III, Firm A would have incurred total development costs of ($490+494.96=984.96$), compared with Firm B's meagre ($90+541.52=631.52$). By $x=15$, Firm A's total development costs are ($490+1362.75=1852.75$), whereas Firm B's are ($90+1778=1868$). The smart thing, of course, would have been for Firm A to make the jump to Generation III technology immediately on discovering that Firm B had switched to Generation II, i.e., after reaching $X=4$. By $X=15$, Firm A's development costs would then be merely ($160+1362.75=1522.75$).

These are very simple, stylised scenarios (for example, we have left out any discounting and we have assumed, in contrast to our capabilities perspective, that each firm is capable of developing a technology to the same cost/performance position) but they do show the usefulness of combining both orthodox (diminishing returns, though here applied to product development) and heterodox perspectives (deficient foresight/myopia, and path dependence). If firms are battling to match each other's standards but product development takes place in historical time, the economics of abandoning commitment to one technology and trying to develop another with better long term prospects vary considerably depending on how far ahead one looks. The firm that delays switching will generate a better cashflow to invest in other areas initially but will eventually fall behind if it does not jump to an even later generation technology whilst rivals have yet to reap the benefits of their earlier switch. A focus on short-term financial performance is likely to lock a firm into technological backwardness. It may make sense to try to skip a generation in technology, but it may be necessary to do this sooner rather than later, particularly if there is an even more advanced technology to which one's rivals might jump. This is a lesson that EMI learned too late with its CAT scanner technology when late-entrant rivals Technicare and General Electric 'leapfrogged' its technology and eventually squeezed EMI out of a market which it had created in the first place (Teece, 2000)).

7 Conclusion

New products typically involve using hybrids of existing technologies or genres to open up new possibilities or to go at least some way towards satisfying unmet needs (Earl, 2003). This paper, rather fittingly, might be seen as a new product in exactly these terms: it is intended to enhance understanding of the economics of product development via a synthesis of basic concepts and modelling tools from orthodox static, equilibrium-focused economics with the general vision of technological competition in terms of shifting aspiration levels, growing product sophistication and capability development from heterodox economics. Normally, the blending of fundamentally different ways of approaching economics might be seen as a recipe for disaster for at least one approach: a case in point might be the 'neoclassical synthesis' version of Keynesian economics, which was viewed by those close to Keynes, such as Joan Robinson, as 'bastard Keynesianism'—analytically neat but a diversion from Keynes's fundamental points. Here, we hope we have laid foundations for a win-win synthesis, not a kind of 'bastard Schumpeterian economics'.

To be sure, the analysis may initially unsettle heterodox economists because the diagrams we have developed look at first sight suspiciously like those from mainstream texts. Well-defined lines clearly give a false precision. However, what we have presented is not designed for capturing the essence of totally unprecedented, truly radical product innovations where, as Foster (2005, p. 882, after Damasio, 1995) points out, decisions to go ahead are essentially emotional, with little recourse to cashflow estimates. We have merely been discussing product *development and improvement* dilemmas and budgeting choices where something akin to what Foster calls 'subjective optimisation' can reasonably be imagined to take place during planning. Entrepreneurs and managers have to imagine what products they might come up with, what revenues they could achieve and how much it would cost to achieve them, at least in broad 'order of magnitude' terms. From such thoughts they can develop arguments to present to suppliers of finance about what they aspire to develop and how much it will cost to do so, or work out what to do with a limited development budget. The framework we have proposed is an abstract but potentially useful way of encapsulating the kinds of mental processes that they go through, or for teaching prospective entrepreneurs and technology managers about the kind of thought process they should go through when taking decisions about what product(s) to try to develop and where to improve existing products.

For orthodox economists, the paper presents a variety of opportunities in territory that might hitherto have seemed not amenable to navigation via their trusted tools. For one thing, it provides something instantly amenable to inclusion in managerial and business economics teaching and yet at the same time is ripe for extension from our two-dimensional graphical version into an n-dimensional mathematical treatment. It also shows that it is perfectly possible to use familiar tools even when picking up notions such as non-compensatory decision rules that are at odds with the core of orthodox economics, or abandoning the notion of a given production function. It may thus help to pave the way towards further work that synthesises orthodox and heterodox perspectives, rather as has happened with the emergence of models of bounded rationality within mainstream economics. If such work adds new vigour to orthodox writings and increases interest in heterodox approaches without losing key messages from the latter, then everyone should welcome it.

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