The Profit Saddle:

Do Unit Cost Reductions Yield Increasing or Decreasing Returns?

(*Running title*: THE PROFIT SADDLE)

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Abstract

When asked about the impact of unit manufacturing cost reductions on total gross profit, many managers and academics assume that returns will be diminishing, i.e., that the first dollar of unit cost reduction will generate more incremental gross profit than the last dollar of unit cost savings, consistent with economic intuition about diminishing returns. The present note shows why total profits actually increase in a convex fashion under typical demand assumptions, providing *increasing returns* with each dollar reduction in unit manufacturing cost. These convex returns are captured graphically in the profit saddle, a simple plot of total profit as a function of unit cost and unit price. Further returns derive from learning curve effects, strategic considerations, quality improvements, and channel benefits. Of course, the fixed investment entailed in reducing unit manufacturing costs must be weighed against the increasing returns from doing so, suggesting some optimal level of unit cost reduction efforts.

Cost reduction has traditionally been the purview of the manufacturing function within the firm, and has been emphasized in the later phases of the product-process life cycle. Marketing managers, on the other hand, have focused on generating sales revenues through pricing policy, product design & positioning, advertising & promotion and channel management. The present note suggests that the traditional view be questioned. We suggest that the marketing function, and new product planning in particular, consider unit manufacturing cost reduction a potent tool in positioning new products for future marketing success.

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How important are unit manufacturing costs in the design and development of new products? Obviously, cost matters, but, typically, the determination of unit cost comes late during the development process, long after many decisions have been taken with respect to the design and feature levels of the new product. After all, how can cost be known until the details of components, parts, manufacturing processes and production volumes have been specified? Yet, there are good reasons to focus on cost reduction *earlier* in the process, and to let the potential for cost reduction guide the choice of product concept and the allocation of resources for its development.

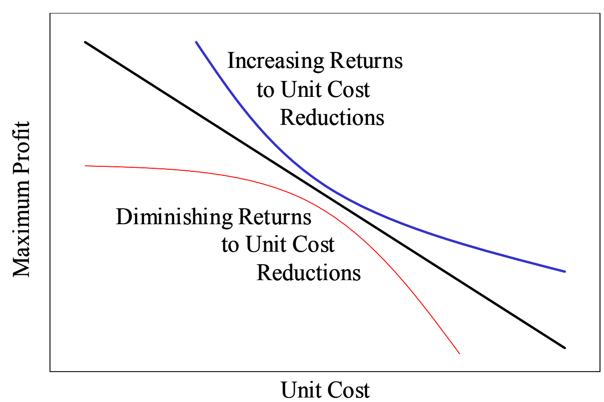
Many questions arise in determining the optimal cost reduction strategy during NPD. For example, should the marketing members of multifunctional NPD teams be concerned with cost-related decisions even though these issues have traditionally been the purview of the engineering and manufacturing functions of the firm? Our analysis shows that, in many cases, marketers should be involved in these decisions from the outset. When should cost reduction be emphasized during NPD? Unlike traditional approaches, our analysis suggests that cost reduction should be considered early in the process, alongside concept selection and the setting of feature levels. What is the profit impact of reducing unit production costs - do incremental cost reductions yield increasing or diminishing returns? We show that within a range, contrary to the economic intuition of diminishing returns, cost reduction has increasing returns. Further, how should cost reduction proceed and how much investment in cost reduction is optimal? Of course the answer here is quite complex, but we suggest that careful concept selection, feature-level setting, target costing, design for manufacturability and assembly, set-based methodologies, and the use of postponement, modularity and platforms can all help.

In this article, we explore the who's, what's, when's, how's and why's of cost reduction during new product development. Our findings regarding the profit impact of cost reduction efforts run counter to many managers' intuitions. We find that early and effective cost savings efforts may improve the chances of new product success to a greater extent than is commonly believed, and that the payoff from unit cost reduction justify significant investment in "smarter" design and should be made early in the NPD process. In fact, the potential for unit cost reduction may be an important criterion when selecting a new product concept from amongst competing ideas.

Increasing or Decreasing Returns?

Consider the three possibilities depicted in Figure 1. In the lower curve, investing in unit cost reduction improves total profit in a diminishing fashion.

Figure 1: Do unit cost reductions Yield Increasing or Decreasing Returns?



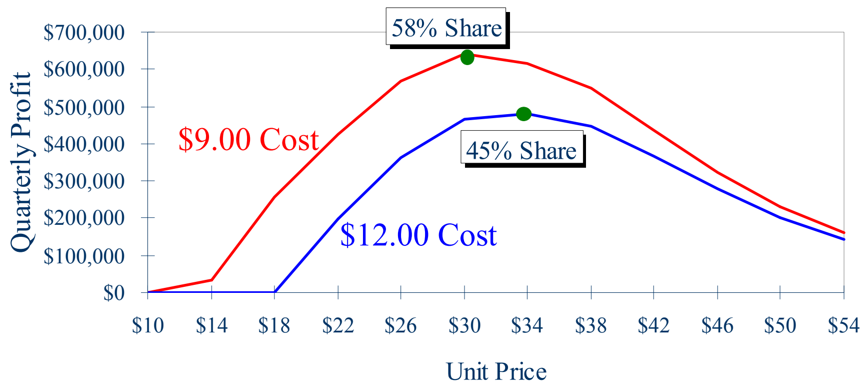
That is, the first dollar of unit cost reduction has a larger impact on total profit than the next dollar of reduction. This fits the general economic intuition of diminishing returns. The middle curve depicts a linear relationship between cost and profit, consistent with the idea that unit costs don't necessarily affect revenues (through lower prices and higher volumes), so the firm reaps additional profits from cost reduction in the form of proportionately higher margins.

Finally, the top curve depicts increasing returns, implying that cost reduction produces benefits beyond simple unit margin improvements at existing volumes, and that prices and volumes must adjust to unit cost reductions in order to maximize profit. It is this third scenario, somewhat counterintuitive to many managers, that our analysis supports. A simple proof follows.

Assumptions:

- [A1] **Downward Sloping Demand**: The quantity demanded, $q(p)$, is monotonically decreasing as a function of price: i.e., $\partial q / \partial p < 0$ for all *p* in the support.
- [A2] **Positive Gross Profit**: Unit cost, *c*, is such that positive gross profits can be generated at some positive price, *p*, in the support of the demand function i.e., $p > c > 0$ for some $q(p) > 0$.
- [A3] **Unique Profit-maximizing price**: The gross profit function, $\pi = (p - c) \times q(p)$, is strictly quasi-concave and smooth in *p*, and therefore has a unique, profit-maximizing price, p^*. See, for example, Figure 2.

Figure 2



Using these assumptions, we first show that optimal prices are decreasing in cost.

Lemma 1: The optimal price is decreasing in cost, i.e., $\partial p^* / \partial c > 0$.

Proof: The first order condition (FOC) for maximizing the gross profit function shown in [A3] is:

(1) $$FOC = \frac{\partial \pi}{\partial p} = \frac{\partial[(p-c)\times q(p)]}{\partial p} = (p-c)\frac{\partial q}{\partial p} + q(p) = 0.$$

By invoking the Implicit Function Theorem at p^*, we see that:

(2) $$\frac{\partial p^*}{\partial c} = -\frac{\partial FOC / \partial c}{\partial FOC / \partial p} = -\frac{-\partial q / \partial p}{\partial^2 \pi / \partial p^2} > 0,$$

since $-\partial q / \partial p > 0$ by [A1] and $\partial^2 \pi / \partial p^2 < 0$ by [A3]. #

Thus when pricing optimally, and given our assumptions about downward sloping demand and sufficiently low unit cost, lower unit costs lead to lower prices.

Lemma 2: Optimal pricing implies elastic demand, i.e., $\varepsilon > 1$.

Proof: Equation (1) can be solved for *p*, giving,

$$(2) \qquad p^* = c - \frac{q}{\partial q / \partial p}.$$

The price elasticity of demand, ε, is defined as the percentage change in volume based on a corresponding percentage change in price:

$$(3) \qquad \varepsilon = -\frac{\Delta q / q}{\Delta p / p} \cong -\frac{p}{q} \cdot \frac{\partial q}{\partial p} \Rightarrow$$

$$-\frac{q}{\partial q / \partial p} = \frac{p}{\varepsilon}$$

Substituting the last expression into equation (2) and solving for p^*, we have:

$$(4) \qquad p^* = c \times \left(\frac{\varepsilon}{\varepsilon - 1} \right),$$

which can only be consistent with [A2] when $\varepsilon > 1$. #

We note that Lemma 2 confirms equation (2). By differentiating equation (4) with respect to *c*,

(5) $$\partial p^* \big/ \partial c = \frac{\varepsilon}{\varepsilon - 1},$$

which is greater than zero for all $\varepsilon > 1$, $\partial p^* \big/ \partial c > 0$ consistent with Lemma 1. We also note that elasticities below 1 lead to infinite prices, thus violating [A3].

Employing Lemma 1, we now show that gross profits have increasing returns to cost reduction, that is π is convex in *c*.

Theorem 1: For any demand function, $q(p)$, meeting assumptions [A1] - [A3], the optimal gross profit, $\pi(p^*, c) = (p^* - c) \times q(p^*)$ is strictly convex in unit cost, *c*. That is, $\frac{\partial^2 \pi(p^*, c)}{\partial c^2} > 0$ and returns to unit cost reductions are increasing.

Proof: Differentiating $\pi(p^*, c) = (p^* - c) \times q(p^*)$ twice with respect to *c*, we have

(6) $$\frac{\partial^2 \pi(p^*, c)}{\partial c^2} = -\frac{\partial q}{\partial p^*} \cdot \frac{\partial p^*}{\partial c}.$$

Since $\frac{\partial q}{\partial p^*} < 0$ by [A1] and $\frac{\partial p^*}{\partial c} > 0$ by Lemma 1, $\frac{\partial^2 \pi(p^*, c)}{\partial c^2} > 0$. #

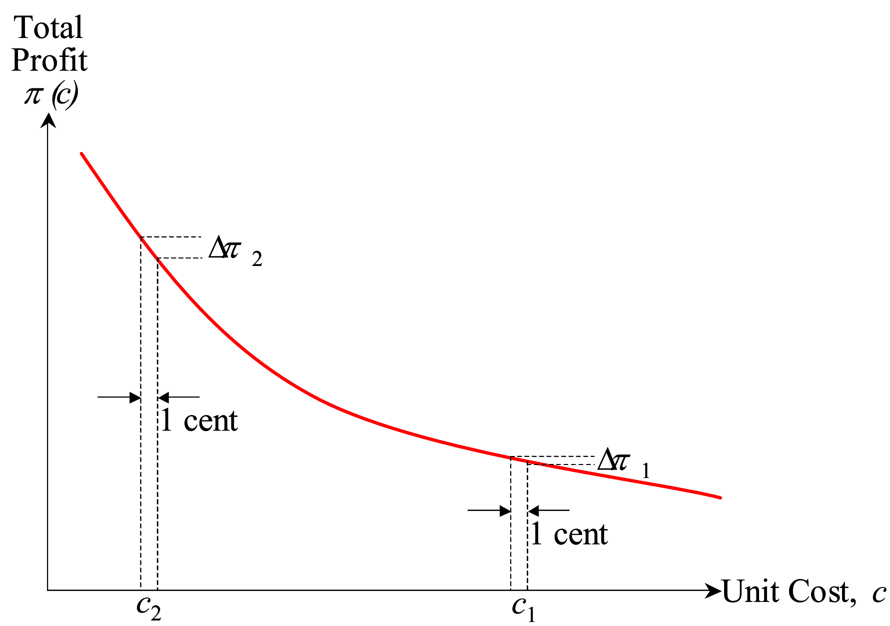
Combining equations (5) and (6), we have:

(6) $$\frac{\partial^2 \pi(p^*, c)}{\partial c^2} = -\frac{\partial q}{\partial p^*} \cdot \frac{\varepsilon}{\varepsilon - 1}.$$

revealing that the degree of convexity of total gross profit with respect to unit cost is a function of the price elasticity of demand at the optimal price point product and the slope of the demand curve at the optimal price (itself increasing in elasticity). In other words, when demand is very price elastic, the convexity result is stronger.

The intuition behind the profit convexity result of Theorem 1 is readily demonstrated in Figure 3. When unit cost is high, as at c_1, reducing that unit cost 1 cent has a small effect on profit since the volumes being sold are small. But when unit cost is much lower, as at c_2, the impact is greater since the 1 cent saving applies to a higher volume of units sold.

Figure 3



We now analyze two well know demand functions, linear and constant elasticity, to illustrate some of the implications.

Examples

As a simple example of increasing returns, assume that a profit-maximizing firm faces demand for a differentiated product (we treat the firm as a monopolist here on the assumption that competitors products are not perfect substitutes) that is linear in price, p, with m being the slope of the demand line, c being the constant marginal cost of production ($0 \leq \text{c} < 1$, consistent with [A2]), and q the quantity sold.

$$\text{Linear Demand Function}: q = m \times (1 - p)$$
$$\text{Profit}: \pi = (p - c) \times m \times (1 - p)$$
$$\frac{\partial \pi^2(c)}{\partial c^2} = \frac{m}{2} > 0 \;\; \text{(i.e. } \pi \text{ is convex in } c\text{)}$$

To maximize profit, π, the firm sets its price at $p^* = \dfrac{c+1}{2}$ and realizes profits of $\pi^*(c) = m\left(\dfrac{(c+1)^2}{4} - c\right)$. The second derivative of profit with respect to unit cost is positive for any negatively sloped linear demand, thus confirming increasing returns to unit cost reductions. As expected, cost reductions lead to price reductions $\left(\dfrac{\partial p^*}{\partial c} > 0\right)$, and volume increases $\left(\dfrac{\partial q^*}{\partial c} > 0\right)$.

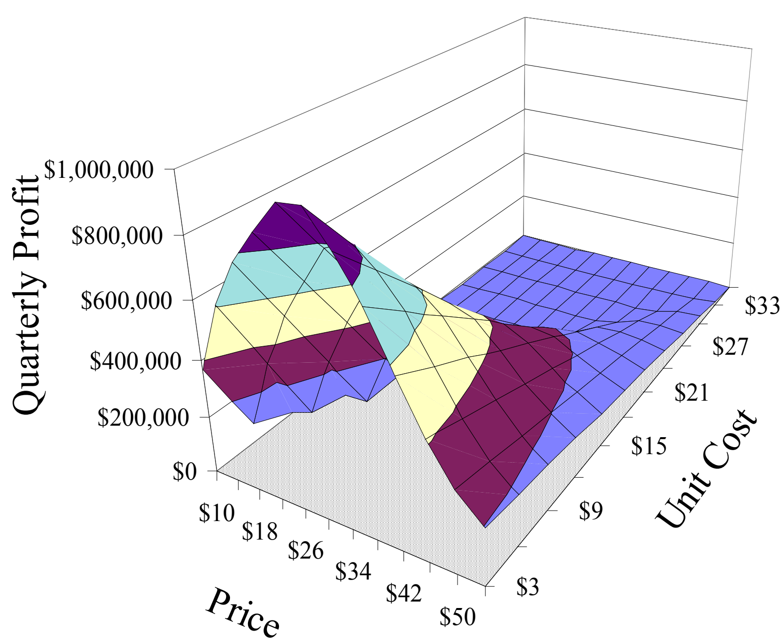
Similarly, the firm may face demand with constant price elasticity, ε.,

$$\text{Demand Function}: q = kp^{-\varepsilon}, (\varepsilon \text{ is constant elasticity})$$
$$\text{Profit}: \pi = (p - c) \times kp^{-\varepsilon}$$
$$\frac{\partial \pi^2(c)}{\partial c^2} = K(\varepsilon - 1)(\varepsilon) \cdot c^{-\varepsilon - 1} > 0 \text{ for } \varepsilon > 1 \;\; \text{(i.e. } \pi \text{ is convex in } c\text{),}$$
$$\text{where } K = \frac{k\varepsilon^{-\varepsilon}}{(\varepsilon - 1)^{-\varepsilon + 1}}$$

To maximize profit, π, the firm sets its price at $p^* = c \times \left(\frac{\varepsilon}{\varepsilon - 1}\right)$ and realizes profits of $\pi^*(c) = \frac{K}{c^{\varepsilon - 1}}$. The second derivative of profit with respect to unit cost is positive for with elasticity greater than one, again confirming increasing returns to unit cost reductions. Again, with higher than unit elasticity, cost reductions lead to price reductions $\left(\frac{\partial p^*}{\partial c} > 0\right)$, which lead to volume increases $\left(\frac{\partial q^*}{\partial c} < 0\right)$.

The relationship between unit cost, optimal pricing and total gross profit can be summarized graphically, as in Figure 4, which we label "The Profit Saddle". The convexity result shows up as the ridge of the saddle, and comprises the set of points at which profit is optimized for each possible unit cost.

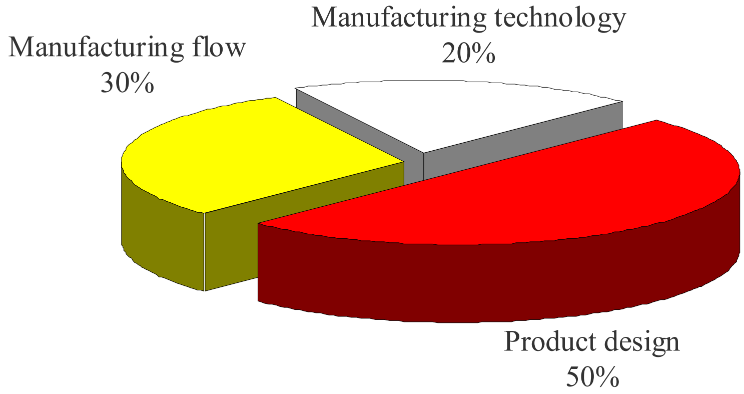
Figure 4: The Profit Saddle



Note how these points illustrate the fact that optimal prices decrease as unit costs decrease, leading to convexly increasing profits.

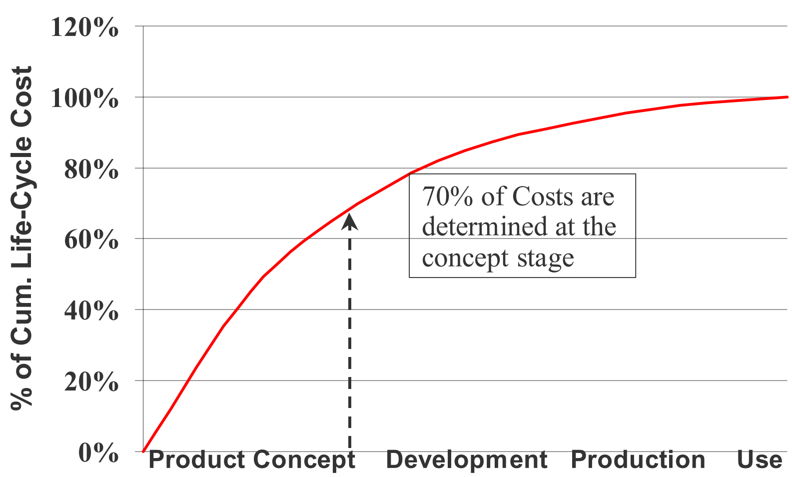
The expression "timing is everything" certainly applies to the process of cost reduction. Unfortunately, many traditional approaches defer cost reduction efforts until late in the NPD process. Typically, many concepts are considered, one is selected and designed in detail, component-by-component and ultimately part-by-part. Then prototypes are built and tested, and a manufacturing process is developed. In concurrent engineering, the process is developed in parallel with the detailed product design, but still well after a design concept has been finalized. The process of actually reducing unit manufacturing costs, for example through design for manufacturability and assembly (DFMA) or improving manufacturing efficiency through production technology or supply chain management, typically comes much later than concept selection. In this case, cost reduction becomes part of a continuous improvement program and follows learning curve principles. But, as Figure 5 illustrates, only part of the potential for cost reduction remains in these latter stages of new product development. A significant portion of the possible reductions in unit manufacturing cost are predetermined by the product design itself - that is they are "built in" to the product concept and not subject to improved manufacturing technology and efficiency.

Figure 5: Manufacturing Savings Opportunities (John Deere & Co. internal study)



Due to the sequential aspect of new product development, the ability to reduce the unit manufacturing cost of a new design may be constrained by concept choice, component design, detailed product and process design. In fact, prior analyses have shown that 70% or more of the unit manufacturing costs of a new product are "locked in" at the time of concept selection (e.g., Nevins, et. al. 1989), as shown in Figure 6.

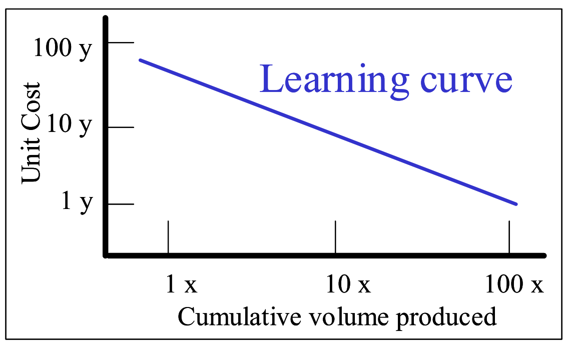
Figure 6: 70% of a product's cost are "Locked-in" by concept selection



Given the importance of cost reduction and the fact that a significant proportion of a product's costs are determined early in the NPD process, one must carefully evaluate cost implications and potential savings *before* committing to a design. Further, the design team may want to allocate a significant part of its development budget to cost reduction rather than committing it totally to performance and quality improvement.

Beyond the price-volume-profit relationship captured by Theorem 1 and the Profit Saddle of Figure 4, there are three additional benefits of designing in lower unit costs early in the new product development process. One of these benefits derives from the Learning Curve, the phenomenon by which cumulative production volumes lead to ongoing decreases in unit cost, as in Figure 7.

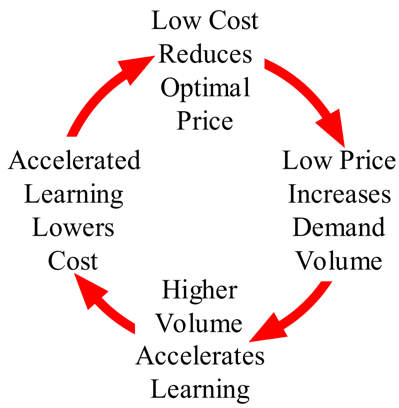
Figure 7: the Learning Curve



Abernathy, 1978

As illustrated in Figure 8, starting off with a lower unit cost through careful design choices early in the NPD process leads to a virtuous cycle in which higher volumes are produced (since the optimal price is lower) early on.

Figure 8



A simple way to thin of this effect is that lowering the unit cost at the design phase gives the firm a "head start" on the competition in its race down the learning curve. This time advantage translates into a higher net present value of the future stream of gross profits.

The second extra benefit of unit cost reduction is, ironically, an improvement in product quality. While intuition might dictate that lower unit cost implies lower quality, research has demonstrated that in some cases, the cost reduction efforts aimed at reducing the number of parts and making assembly more efficient and consistent may also reduce the number of failure modes of the product, thereby increasing quality. See Figure 9, for example.

Figure 9

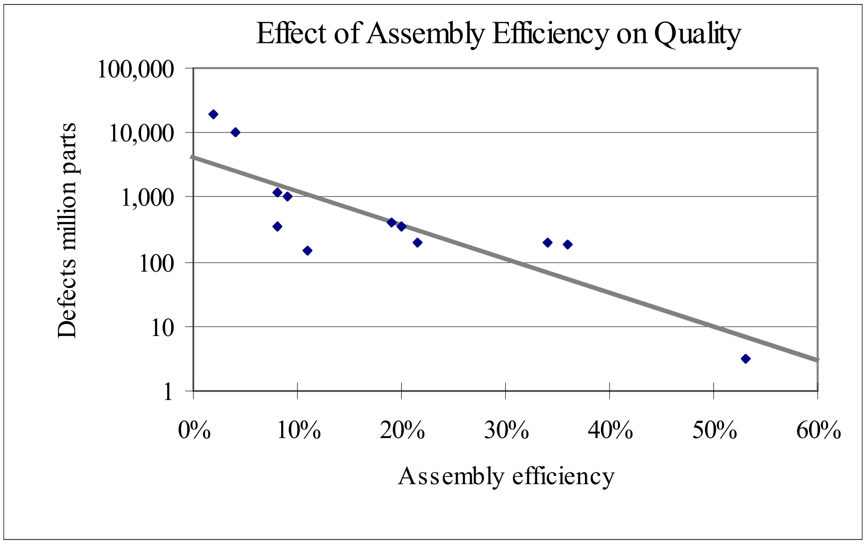
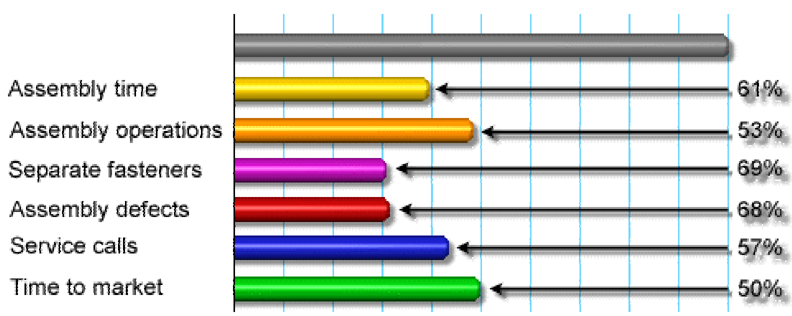


Figure 10 provides data from the leaders in design for manufacturing and assembly, Boothroyd and Dewhurst, claiming that efforts at reducing unit costs through DFMA not only reduce costs through faster assembly and fewer parts, but also reduce assembly defects and the need for service calls, consistent with the improved quality argument above.

Figure 10

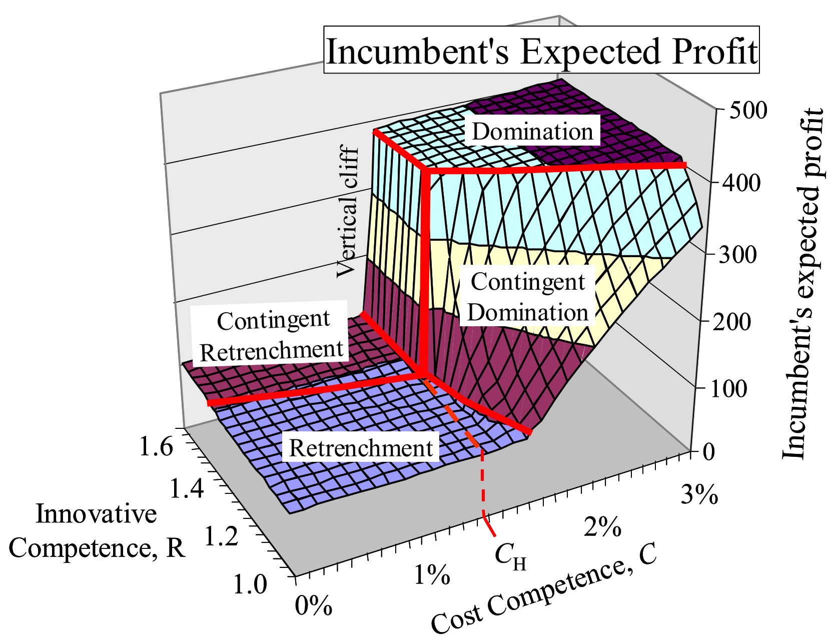


They further make the claim that time-to-market may also be halved since the process of ramping up production becomes much easier when the product design has been optimized for manufacturability. Clearly, if product quality and reliability are improved and time-to-market is shortened, profits should improve as well.

Of course, we put forth the caveat that while unit cost reduction efforts may improve quality on some dimensions such as reliability and serviceability, they may hinder other forms of quality. For example, while a low cost digital watch may keep time perfectly with very few parts in its design, a much more costly watch featuring a precise jeweled mechanical movement from Switzerland may be perceived as being of much higher quality. In fact, it is well established in the conjoint analysis literature that some respondents impute higher quality to full-profile bundles of attributes with higher prices, even after being told that all other attributes are held constant.

The third extra benefit of unit cost reduction is a strategic one and is depicted in Figure 11, based on research by Schmidt and Porteus.

Figure 11



When the firm establishes itself as the low cost manufacturer in a given product category, it may dissuade competitors from entering the market, leading to significantly higher profits. The ability to develop and manufacture products at lower unit costs than competitors, here captured by the cost competence factor, C, may be as important as the ability to develop more innovative products, captured by R. By being competent at unit cost reduction, incumbent market leaders are able to keep potential entrants at bay.

In summary, unit cost reduction early in the design process has been shown to have increasing returns due to the Profit Saddle effect, and extra benefits due to the virtuous cycle of the learning curve, potential quality improvements, and strategic effects.

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