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Toward Meso-level Product-Market Network Indices for Strategic Product Selection and (Re)Design Guidelines over the Product Life-Cycle

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Many methods to arrive at a product-market choice through selection and (re)design assume stationary demand and a stable range of products to pick and maximize profit trading off operational performance in manufacturing versus (under)servicing certain market segments. The determination and decisiveness in the product-market choice and marketing and manufacturing strategies are likely to be different when anticipating technological change and (ensuing) shifts in demand and competition of which the timing and direction is often uncertain. As the product life-cycle pattern describes such changes in market, technology and competition over time, we can use the stylization thereof to derive strategic and forward-looking product selection and (re)design decisions. We introduce the notion of a meso-level product-market network and two indices to quantify features of that network. We then relate index values over time to phases in the meso-level product life-cycle to derive micro-level, forward-looking product selection and (re)design guidelines that anticipate developments in the industry. We also uncover the different roles of the marketing and engineering departments in the various product life-cycle phases.

Keywords: Product-Market Network; Product Selection and Design; Network Index; Marketing-Manufacturing Interface; Technological Change; Product Life-Cycle

1. Introduction

Firms are engaged in product selection and (re)design to isolate the profitable product-markets to target. We take each firm to consist of a marketing department compiling demand information on market segments and deciding which service characteristics to provide, and an engineering department realizing the operational product design and manufacturing the products (efficiently). The methods used to derive the product-market to target mostly (implicitly) assume stationary demand on various segments and a range of stable product technologies to chose from. However, technological innovations and (ensuing) changes in demand and the competitive landscape evidently affect such a product-market choice. Given the conceptual complexity of the problem at hand, it is not surprising that in product design and selection literature, 'taking into account the demand market and competition' is a long-standing and frequently reiterated topic on the research agenda (See e.g. Mather 1986, Ye *et al.* 2009).
When such market shocks or technological breakthroughs are bound to happen and can

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hence be anticipated, simply rerunning existing methods to account for industry conditions after such a shock or shift is not dynamically efficient. However, uncertainty about the timing and direction of such shocks complicates formulating a static, off-line method, but requires a dynamic, on-line method involving the marketing and engineering interaction.

We argue that information on timing and direction can be gathered by transcending the *micro-level* outlook on the product-market choice to a *meso-level* outlook on the product-market *network* spanned by the product-market choices of the focal firm and its competitors. Furthermore, as developments in the product technology, market and competitive landscape follow a life-cycle, we know what patterns to expect and hence account for in decisions.

The goal of this paper is to provide *micro-level* selection and design guidelines that take into account anticipated *meso-level* changes in technology, market demand and competition over the product life-cycle. More specifically, we -true to the tradition of product line and product family design methods- propose indices that convey information on the meso-level product-market network and by reflecting on their typical development allows us to prescribe *strategic* product design guidelines.

In section 2, we provide a short overview of the product design and product life-cycle literature. In section 3, we elaborate on the method how to use indices to isolate the development of the product-market network over the product life-cycle and how this subsequently translates to micro-level design guidelines. In section 4, we develop the two indices on the meso-level product-market network. In section 5, we speculate on how measurements develop over the product life-cycle and how this translates to product (re)design guidelines to be followed by *individual* firms and the roles of both the marketing and engineering department to play. In section 6, we conclude.

2. Background on product selection and design decisions

With regard to product selection and design literature, we discern two perspectives. The first perspective is the New Product Development literature (e.g. Ulrich and Eppinger 2004, Magrab *et al.* 2010), which is concerned with low-level methods to operationally organize an off-line, linear product development process (in which selection and design are very prominent), often run by a multi-disciplinary team consisting of engineering and marketing department envoys. Developing a new product starts with gathering needs from customers, translating them into specifications and using those in turn for product concept generation and selection. After product selection, the architecture and detailed designs are decided upon and production facilities are established. A detailed overview of decisions to be taken by the marketing and engineering departments in defining a product is given in Krishnan and Ulrich (2001).

The second perspective concerns on-line, non-linear and interactive product portfolio management in terms of product (de)selection and (re)design. In the product selection process, the marketing department answers the question *'what products to make for whom?'*, thus brokering customer requirements into service characteristics, while the engineering department establishes the technologically feasible specifications thereof in answering the interlocking question *'what products can we make and how?'*. We assume that both departments have a 'common interest' to comply with a sufficiently articulated product-market developing strategy[1]. A shared concern of maximizing profit then has the marketing department seek to increase sales margins by adjusting service characteristics and market segments targeted and the engineering department seek to decrease manufacturing costs by adjusting technical characteristics and production facilities used, both across the total product portfolio. The ideal case is a buyers' market (Erens and Hegge 1994) in which individual customers' needs are satisfied at mass-production efficiency (Jiao *et al.* 2000). However, these two objectives are not perfectly aligned, forcing a trade-off between sales margin and operational performance. We find that both marketing and operations management research tackle their respective 'what' and 'how' questions in product selection and design in isolation. We thus arrive at two steps in a piecemeal approach to product selection and (re)design.

For the first step, investigated in marketing literature, technological constraints are ignored and service characteristics embodied in the product concept are matched with consumer preferences. Product attributes (including price) are factors in (multinomial) consumer choice models, such that optimization involves solving a program to find the product design (set of attributes) that maximizes profit (for an overview, see Kaul and Rao 1995), possibly involving multiple market segments and multiple products (see Green and Krieger 1989).

The second step, investigated in operations management and operations research literature, is to take market demand as given (and generally stationary) to jointly design the product and its production process (for a detailed treatise see e.g. De Lit and Delchambre 2003). As the bill-of-material is tightly coupled to the organization of production (Mather 1986, Hegge and Wortmann 1991), manufacturing efficiency depends on the product design, portfolio and variety. Hence, in deciding on the product portfolio, firms balance production efficiency realized by standardization, commonality and postponement with disutility of underservicing certain segments (Rutenberg and Shaftel 1971, Kim and Chhajed 2000). Operations research is currently endeavoring the incorporation of market information into product and production (re)design decisions. Particularly product line and product family methods that employ commonality methods (Collier 1981) have advanced to include (static) production volumes (e.g. Jiao and Tseng 2000, Wacker and Treleven 1986), marketing-specified variety/ commonality ratio requirements (Ye *et al.* 2009) and optimization under the trade-off between sales and costs (Day and Venkataramanan 2006, Chen *et al.* 2009), and even joint optimization of production efficiency versus expected demand as functions of pivotal product characteristics (Kumar *et al.* 2009).

Concurrent or iterative selection of service characteristics to provide and the actual design of products is likely to be required as the choice of one defines the feasibility region (and object function) of the other (Piedras *et al.* 2006).

Arguably, changes in demand figures can be dealt with by rerunning aforementioned methods, even taking into account cross-portfolio-commonalities (see Chen *et al.* 2009). The same arguments might hold for incremental changes in required service characteristics by e.g. introduction of 'evolutionary new products' by competitors (Kaul and Rao 1995). However, *uncertainty* on market demand keeps firms from finalizing product designs and rather obtain more information on customers' preferences (Bhattacharya *et al.*

[1] And, indeed, we assume that the strategic design guidelines we provide later are of such nature. Note that, in case of 'opposite interests', concerns can be aligned through conflict resolution methods (Crittenden *et al.* 1993), conceptual discussion frameworks (Berry *et al.* 1999), shared costs trade-off models (De Groote 1994) and financial incentive schemes (Porteus and Whang 1991).

1998). Moreover, as firms *compete* on innovations to capture new sales of own and competitors' customers (Schumpeter 1942), product selection and (re)design research requires an evolutionary look on industry dynamics (a first leap is taken in Loch and Kavadias 2007).
However, rather than a perpetuate stream of innovations and (thereby induced) shocks to market demand and competitive landscape with unknown timing and direction, industries go through a product life-cycle[2]. The punctuated product life-cycle theory (Anderson and Tushman 1990) states that each industry cycles through eras of ferment and eras of incremental change, where transitions between the two are punctuated by emergence of a so-called dominant design and a technological breakthrough. In the era of ferment, firms face a new market opening up, and rather than to freeze, waiting for more information, they compete on experimental product variants hoping to win the market. Firms do so despite the foresight of inevitable shocks to market demand and technology to be mastered. As research is costly and inherently uncertain, innovators first seek to exploit the market potential and appropriate returns. Once a certain technological variant has accumulated a bundle of characteristics sufficiently attractive to the lion-share of customers (Suárez and Utterback 1995), producers of that variant take the risk to standardize product technology and upscale capacity to enjoy economies in production, demand and research (Klepper and Simons 2005) that also accrue to customers and thus drives further diffusion. Competitors generally cheaply imitate such a successful innovation, or are forced to exit the industry in a shakeout. After emergence of such a dominant design (Utterback and Abernathy 1975), innovation becomes incremental and competition further revolves around price, costs and efficiency, and hence focus is generally on process innovation (Utterback and Abernathy 1975). Breakthrough innovations, sought after by existing players facing dwindling profits or external parties trying to leapfrog incumbents, catapult the industry into a new era of ferment.

Entry *before* emergence of the dominant design considerably increases chance of survival (Suárez and Utterback 1995, Klepper and Simons 2005, Christensen *et al.* 1998, Agarwal 1997); afterwards, incumbents already enjoy the advantages of their scale, established channels and brands. So, arguably, *sustained presence* requires a balanced mix[3] of cash-generating products in mature industries and cross-financed promising products in emerging industries is required. As firms thus necessarily have to be engaged in risky product research in the fermentation phase, this immediately underlines the importance of selection and design guidelines that strategically anticipate *meso-level* market and technology developments in such a product life-cycle pattern.

Harking back to the first perspective discerned, Figure 1 hints that the four depicted product development projects (irrespective of iterations in defining the product) should lead to different decisions on finalization and dedication of product design, portfolio and production. Technological progress, if accounted for, is taken as a sigmoidal growth curve in one or a few performance parameters and predictable enough to incorporate in near-future design efforts through a technology roadmap (Ulrich and Eppinger 2004). Given

[2]Nota bene: this differs from the product life-cycle concept as used in product design literature in which is referred to the phases *a single unit of a product* goes through and how the producer and supply chain are involved in this, e.g. design, assembly, consumption and after-sales service, disassembly and recycling (e.g. Saaksvuori and Immonen 2003, Prudhomme *et al.* 2003, Sy and Mascle 2009). The product life-cycle we refer to here concerns experimentation, growth, maturation and decline in industrial production and market usage of the product concept. For an elaborate discussion on the difference of the two, see Suomala (2005).
[3]The composition of the product development project portfolio itself also matters. Wheelwright and Clark (1992) provide an 'aggregate project plan' method to guide the balancing of this portfolio.

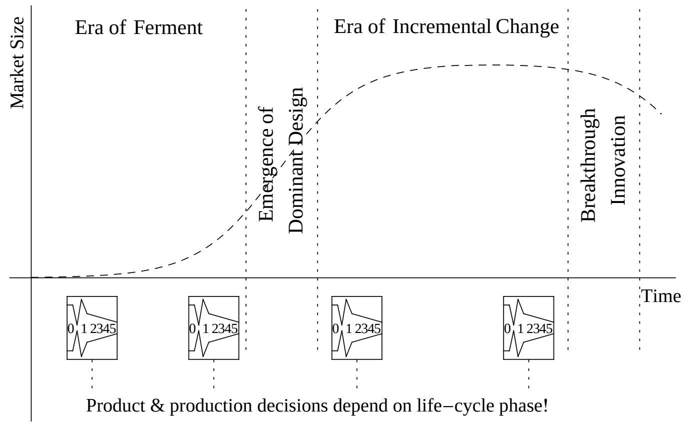


Figure 1. Impression of the punctuated product life-cycle with the hint that product selection & design and production decisions as taken in the Ulrich and Eppinger (2004) product development process differ over the life-cycle

the already detailed and involved methods, extension with genuine meso-level technological and market uncertainty is troublesome.

With regard to the second perspective discerned, we see that the operations management and marketing literature provides (index based) tuning of product portfolio and individual designs to optimize profits taking into account production costs and prospected sales per segment. However, the bold presumptions required render the alterations thus derived cost-effective only under negligible meso-level developments in market demand and technology.

On the other hand, product life-cycle literature describes the industry dynamics through meso-level interaction but is largely descriptive and phenomenological and does not readily facilitate micro-level decision support on (re)designing and (de)selecting products.

In the present paper, we put a step forward in bridging these three fields.

3. Method

This paper is to provide a method for an individual firm to pick the recommended product selection and design decision guidelines. Our method is rooted in consumer theory linking service characteristics with technical characteristics of products (Lancaster 1966, Windrum *et al.* 2009), and revolves around the notion of the emergence of a dominant design, i.e. the convergence to a large product-market combination. A design is dominant if a certain percentage of product designs available has the same set of technologies for certain core components (Murmann and Frenken 2006), thereby meeting a set of crucial service characteristics. Closely related to this 'component technology' definition, Frenken (2006) takes the operational principle of products to classify designs and isolate the dominant design.

After certain events and regular intervals, the engineering department of a firm compiles a list of product classes (classification based on core technologies used in the products) offered by the firm itself and competitors, and the marketing department compiles a list of market segments on the basis of service characteristics (as required by the customers that populate the segment). Subsequently, the sales volume of each of the class of products in each of the market segments is estimated. The firm thereby constructs a meso-level product-market network. Next, the proposed network indices are computed to read the industry phase-based recommended design guideline from a coarse[1] look-up table using the computed values.

By conducting this procedure repeatedly, the firm can hence adjust its selection and design activities on the basis of meso-level product-market developments in the industry.

The *research* method to arrive at this look-up table is to use historical data of several complete product life-cycles to compute the development of indices over time and to hook in the design activities of successful firms in the industry (which can both be pinpointed by industry experts). One thus arrives at links of indices values with recommendable design activities.

As a work-around for the empirical analysis, and for more rooting in theory, we use the punctuated product life-cycle (which provides indications on pending technological and industrial changes) and speculate on the development of the product-market combinations, thereby arriving at stylized development patterns of the values of the indices. We then derive recommendations on design guidelines by looking forward to the changes that are pending according to the product life-cycle theory. Note that any (dynamic and cross-sectional) business strategy theory should fit within this framework, theoretically.

4. Product-market network indices

In this section, we develop two indices that quantify two complementary dimensions of the bipartite *meso-level* product-market network[1] as depicted in Figure 2, featuring nodes of market segments and nodes of product classes

The level of aggregation of market segment and product class dependent on the industry classification level. With a high-level industry definition like 'the energy generation industry', common product classes are e.g. 'photo-voltaic cells', 'wind turbine', 'nuclear power plant' et cetera, while market segments are e.g. 'use at home' and 'industrial scale'. A low-level industry definition like 'aircraft for military purposes with horizontal take-off', has market segments 'cargo', 'bomber', 'fighter' and 'trainer', with product classes based on engine type 'turboprop', 'turbofan', 'jet', 'piston prop' and 'rocket' (taken from Frenken 2006, p.108).

Here, we propose two dimensions catching elementary properties of the network structure, which we coined 'vergence' and 'parallelity'. Vergence, discussed in subsection 4.1, covers the extent to which the network is converging (different classes of products target the same market segments) or diverging (the same classes of products are used in different market segments). Parallelity, discussed in subsection 4.2, covers the extent to which certain classes of products and market segments are exclusively linked. The extremes are that the various market segments each has its particular class of product, i.e. there is 'perfect parallelity' and that all different segments use all classes of products in equal shares, i.e. there is 'complete cross-usage'.

[1] 'Coarse' because like as with many quantitative methods, conclusions are of the quality and at the level of aggregation of the input data.

[1] We emphasize that our indices capture elementary features of any bipartite network and we hence expect that it can be used in a great many different settings, e.g. assess buyer-supplier networks, meso-level product-component networks, et cetera.

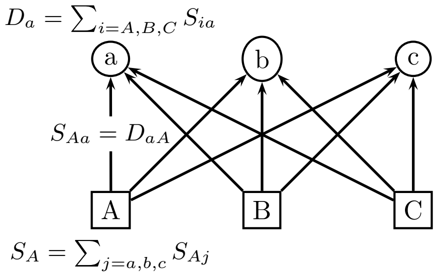


Figure 2. A graphical representation of the relationships between product classes (squares) and market segments (circles). The figures below the squares indicate the total sales S_i of product class i. The figures over the circles indicate the total market size D_j of segment j. The figures on the arcs indicate both the market size D_{ij} in segment i of product class j as well as the total sales S_{ji}

Let $\mathcal{M}$ be the set of market segments and $\mathcal{P}$ the set of product classes. The indices will weigh according to 'volumes'. Towards this end we introduce the following variables. Let S_{ij} be the total sales (in number) of products of class i sold to market segment j, and $S_i = \sum_{j\in\mathcal{M}} S_{ij}$ the total sales of product class i. Likewise, D_{ji} $(= S_{ij})$ is the absolute market size (in number) in segment j of product class i, and $D_j = \sum_{i\in\mathcal{P}} D_{ji}$ is the market size of segment j in the total market.

4.1. *Vergence*

One dimension of the product-market structure concerns whether there is convergence or divergence of the use of product classes in market segments. If the various classes of products each are used in a wide variety of market segments, there is divergence. If the various segments each use a wide variety of product classes, there is convergence.
In expressing divergence, we note that if the total sales S_i is to a single market segment j, there is no divergence, and if the total sales S_i is to a great many market segments, there is great divergence. An intuitive idea is to use the ratios S_{ij}/S_i.
The divergence index $\overline{V}$ measures the fractioning of sales:

$$\overline{V}^p = 1 - \sum_{i\in\mathcal{P}} \frac{S_i}{S} \sum_{j\in\mathcal{M}} \left(\frac{S_{ij}}{S_i}\right)^p \tag{1}$$

As the last sum is normalized, we weigh the contribution of that sum for the various product classes according to the share in total sales S_i/S. We introduce a parameter $p \geq 1$ to tune the penalty for fractioning of the sales. If there is fractioning, then the index will be lower for higher p. Under the extreme condition that there is one product class that is used in $M > 0$ market segments (with equal shares), so the product class is generic, then $\overline{V}$ goes to $1 - M(1/M)^p = 1 - (1/M)^{p-1} = 1$ asymptotically for M for every $p > 1$. Under the extreme condition that there are $M > 0$ product classes each used in a single market segment (highly *convergent* network), then $\overline{V}$ is $1 - M1/M1^p = 0$, regardless of p and M. Note that this means that the divergence index does not pick up on whether a certain market segment uses different product classes, so is insensitive to convergence.

In expressing the convergence, i.e. the extent to which certain market segments use a wide(r) variety of product classes, we depart from the basic idea that if many different product classes i are used in the market segments j, there is strong convergence, while if all market segments j use a single product class i, there is no convergence. An intuitive idea is to use the ratios S_{ij}/D_j.
The convergence index $\underline{V}$ measures the fractioning of the market demand:

$$\underline{V}^p = 1 - \sum_{j \in \mathcal{M}} \frac{D_j}{D} \sum_{i \in \mathcal{P}} \left(\frac{D_{ji}}{D_j} \right)^p \tag{2}$$

Note that $D_{ji} = S_{ij}$. As the last sum is normalized, we weigh the contribution of that sum for the various market segments according to the market share D_j/D. The parameter p is again used to penalize the fractioning of the demand fulfillment.
Under the extreme condition that there is one market segment that uses M product classes (in equal shares), then $\underline{V}^p = 1 - M(1/M)^p = 1 - (1/M)^{p-1}$, which is 1 asymptotically. Under the extreme condition that there are M market segments that use one product class, then $\underline{V}^p = 1 - M1/M1^p = 0$ regardless of M. This means that the convergence index does not pick up divergence.

We combine these two indices into the aggregate vergence index V^p by subtracting the divergence $\overline{V}^p$ from the convergence $\underline{V}^p$:

$$V^p = \sum_{j \in \mathcal{M}} \sum_{i \in \mathcal{P}} \frac{S_{ij}^p (S_i D_j^p - D_j S_i^p)}{S S_i^p D_j^p} \tag{3}$$

Vergence V lies in the range $[-1, 1]$ and is positive if the network converges, negative if the network diverges and is (near) zero when there is relatively as much convergence as there is divergence.
If there is one product class and M market segments, each with a demand of 1, divergence $\underline{V}^p$ equals 1, while convergence $\overline{V}^p = M^{(-p+1)}$ goes to 0, asymptotically. Therefore, the vergence V^p is close to -1 if M is large. Something similar holds for a network consisting of M product classes each selling to a single market segment with demand M, where convergence $\overline{V}^p = M1^p/M = 1$, divergence $\underline{V}^p = M^{(-p+1)}/1$ goes to 0, asymptotically. The vergence V^p approaches 1 if M becomes large.

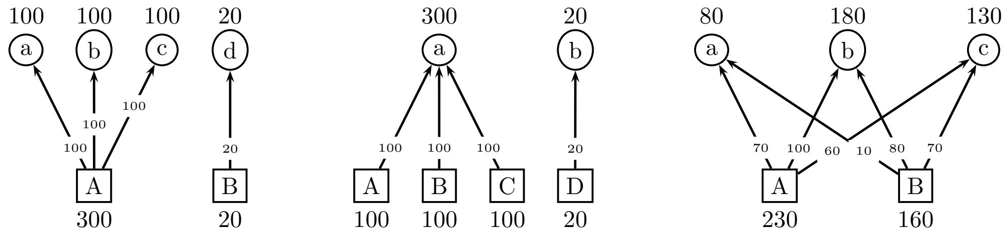
Table 1 contains the measured values of divergence, convergence and vergence for the examples given in Figure 3, where the flow in 3(a) is strongly divergent, 3(b) is strongly convergent and 3(c) has features of both.

The vergence index does have some shortcomings. First of all, vergence does not reflect the number of segments but it does reflect -to some extent- the asymmetries in the number of market segments and number of product classes.
Secondly, vergence is well able to isolate (relatively strict) convergence and (relatively strict) divergence, the index is somewhat insensitive to mixed forms, especially if the market segment sizes are strongly asymmetric.
We investigate the sensitivity of the vergence index with stylized product-market network with two product classes and two market segments depicted in Figure 4.

The convergence value increases if the product classes are demand by a market segment in equal numbers. In case of asymmetric market shares ($\gamma = 0.1$), the convergence measure is particularly sensitive for changes in fractions of the use of product classes in

Table 1. Divergence, Convergence and Vergence values for the networks given in Figure 3 with $p = 3$

	Divergence $\overline{V}^p$	Convergence $\underline{V}^p$	Vergence V^p
Divergent network 3(a)	$1-\frac{30}{32}3(\frac{1}{3})^p-\frac{2}{32}1^p=\frac{5}{6}$	$1-3\frac{10}{32}1^p-\frac{2}{32}1^p=0$	-0.83r3
Convergent network 3(b)	$1-3\frac{10}{32}1^p-\frac{2}{32}1^p=0$	$1-\frac{30}{32}3(\frac{1}{3})^p-\frac{2}{32}1^p=\frac{5}{6}$	+0.83r3
Mixed network 3(c)	$1-\frac{23}{39}((\frac{7}{23})^p+(\frac{10}{23})^p+(\frac{6}{23})^p)-\frac{16}{39}((\frac{1}{16})^p+(\frac{8}{16})^p+(\frac{7}{16})^p)\approx 0.84$	$1-\frac{8}{39}((\frac{7}{8})^p+(\frac{1}{8})^p)-\frac{18}{39}((\frac{5}{9})^p+(\frac{4}{9})^p)-\frac{13}{39}((\frac{6}{13})^p+(\frac{7}{13})^p)\approx 0.66$	-0.18



(a) Divergent network in which several market segments use the same product class

(b) Convergent network in which a certain market segment uses different classes of products

(c) Mixed network

Figure 3. Examples of product-market networks with the sales and market size data.

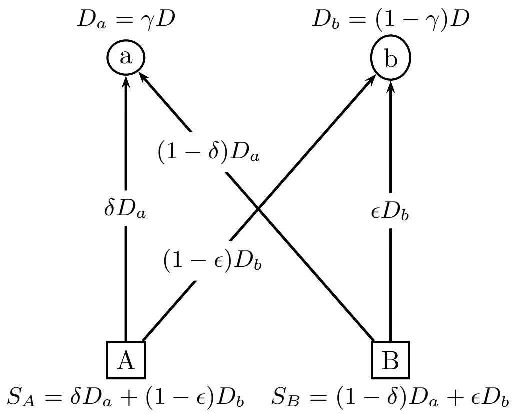


Figure 4. The stylized product-market network used for the sensitivity analysis. Here, arc loads depend on δ and ϵ, with total market size D and actual segment size dependent on γ given

the large market segments. We indeed see that the curve in the subfigure in the top-left of Figure 5 is sensitive to changes in ε and less so to changes in δ. In case of symmetric market shares ($\gamma = 0.5$), the convergence measure is equally sensitive to changes in one or the other 'loading factor' (i.e. δ or ε), which we see confirmed in the bottom-left subfigure.

As we see in the two middle subfigures in Figure 5, the divergence measure is highest and at the same time particularly insensitive on the line $\delta = 1-\varepsilon$. The extreme loading factor cases are easy to understand. Say $\delta = 1$, i.e. segment a exclusively uses product class A, then divergence is at its maximum if the other segment also uses the same product class exclusively and hence $\varepsilon = 0$. Generally, the per product class divergence contribution is at its maximum if all segments use the same share of each of the product classes (for A this means $\delta D_a = (1-\varepsilon)D_b$). Furthermore, at that line, the divergence is $1-\gamma^p-(1-\gamma)^p$, hence independent of δ and ε. Due to our choice of network, the divergence measure can indeed not be high if the market share is strongly asymmetrical; one of the segments receives the lion share of products.

We see in the right column of Figure 5 that vergence, in our simple network, closely reflects the qualities of convergence. It too is insensitive to the convergence contribution of a small market segment (with $\gamma = 0.1$ this is segment a) and divergence is naturally low in case of asymmetric segment sizes.

Under equal market segment sizes, the equal vergence values on the line $\delta = \varepsilon$ is particularly striking. The vergence measure does not pick up on whether market segment a uses a certain product classes exclusively or mixes the available product classes in some fraction, as long as market segment b does the same. In the next section, we develop a parallelity index that in fact is informative especially in this case of different levels of cross-usage (in Figure 4 $\delta \approx \epsilon$ for some arbitrary value).

4.2. *Parallelity*

Parallelity captures the extent to which certain segments have exclusive relationships with product classes. The index should furthermore be sensitive to the actual shares of product classes, even in cases of neutral vergence. In Figure 6, the two extreme cases of parallelity are depicted. Firstly, in 6(b), all segments use all product classes, and, if the market shares are equal, parallelity is 0. Secondly, in 6(a), each segment uses exactly one product class, and, if the market shares are equal, parallelity is 1.

Again, the basic idea is to use the fractioning of shares to isolate the most common segment-class pairs per product. Given the set of product classes $\mathcal{P}$ and the set of market segments $\mathcal{M}$, and the set of viable pairs $C = \{(i,j) \mid i \in \mathcal{P}, j \in \mathcal{M}, D_{ji} > 0\}$ (note $D_{ji} = S_{ij}$), we have to find a set J of size $\min\{|\mathcal{P}|, |\mathcal{M}|\}$ containing pairs with high sales fractions. The sales fractions S_{ij}/S_i for $(i,j) \in J$ is then an expression of the degree to which the segment-class combination is exclusive *from the product class perspective*, while the market share $D_{ji}/D_j = S_{ij}/D_j$ for $(i,j) \in J$ is an expression of the degree to which the segment-class combination is exclusive *from the market segment perspective.* We now propose to take the product of these two fractions to express parallelity from both perspectives. Raising it to the power p facilitates penalizing fragmentation. By further attaching a weight S_{ij}/S to each fraction, the contribution to parallelity is proportional to the relative 'popularity' of a segment-class combination. We arrive at the following

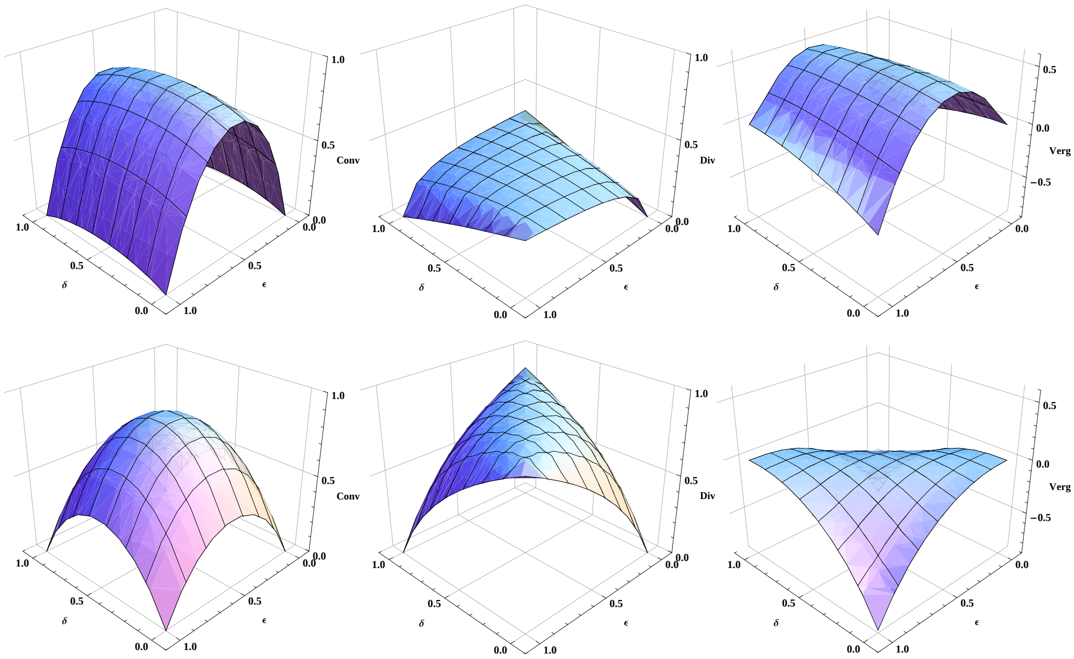
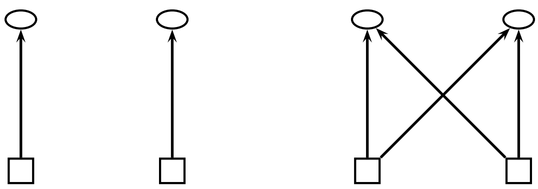


Figure 5. Plots of convergence $\overline{V}^p$ (left column), divergence $\underline{V}^p$ (middle column) and vergence V^p (right column) for a market share scenario with $\gamma = 0.1$ (top row) and with $\gamma = 0.5$ (bottom row). Values ϵ and δ furthermore tune the sales fractions over arcs from product classes to market segments. Here, $p = 4$.



(a) Each segments uses only one product class. Parallelity is 1.

(b) Each segment uses all product classes. Complete cross-usage and parallelity is low.

Figure 6. Two extreme examples of parallelity in product-market combinations

definition of (unnormalized) parallelity:

$$U^p = \sum_{(i,j)\in J} \frac{S_{ij}}{S} \left(\frac{S_{ij}^2}{D_j S_i} \right)^p \tag{4}$$

There are two obvious ways to find J: through a greedy picking or a maximum matching algorithm. Following a greedy picking algorithm, one would pick the arcs with the 'heaviest' fractions from C one-by-one and each step remove all arcs from C pointing to the market segment and from the same product class as the arc just picked. The maximum matching algorithm would pick from all possible combinations the set of arcs with unique product class and market segment such that the total weight is maximized. Irrespective of the algorithm used, we know that $J \equiv C$ in the perfectly parallel case, and $|C \setminus J| = |\mathcal{P}||\mathcal{M}| - \min\{|\mathcal{P}|, |\mathcal{M}|\}$ in the complete cross-usage case.
It is trivial to see that the set of solutions $\mathcal{S}_{GP}$ evaluated by the greedy picking algorithm is completely contained in the set of solutions $\mathcal{S}_{MM}$ evaluated by the maximum matching algorithm ($\mathcal{S}_{GP} \setminus \mathcal{S}_{MM} \equiv \emptyset$), such that in maximizing U^p as defined in eq. (4), greedy picking does not outperform maximum matching.

Although parallelity is able to attain a maximum value of 1, parallelity does have a non-trivial lower bound U^*. To be able to universally cross-compare parallelity values, we normalize this parallelity index. We have to determine this lower bound U^* and, as we will find out, it in fact does depend on the network structure in a surprisingly simple way.
We first prove a lemma that for a particular simple polynomial of variables in $\mathbb{R}^+$, the minimum is attained when all variables are equal.

Lemma 4.1: *The sum $W_z(R) = p_{1z}^n + \ldots + p_{zz}^n$, with $p_{iz} > 0$ and $\sum_{i=1}^{z} p_{iz} = R > 0$ and $n \geq 1$, attains its minimum in $p_{iz} = R/z$.*

Proof: For $z = 2$, $W_2(R) = (R\gamma)^n + (R(1-\gamma))^n$ attains its minimum in $\gamma = 1/2$, so $p_{12} = p_{22} = R/2$. Now, suppose for $z-1$, $W_{z-1}(R)$ attains its minimum in $p_{i(z-1)} = R/(z-1)$. Note that $W_{z-1}(R)C$ for some constant $C > 0$ also attains its minimum in $p_{i(z-1)} = R/(z-1)$. For any $z-1$ of the terms in $W_z = p_{1z}^n + \ldots + p_{(z-1)z}^n + p_{zz}^n$, these $z-1$ p_{iz} values add up to some δR. We know that the minimum for these $z-1$ terms is attained when evenly distributing δR over these $z-1$ p values, i.e. each of the p_{iz} values is $\delta R/(z-1)$.
We rewrite $W_z(R) = W_{(z-1)}(\delta R) + ((1-\delta)R)^n$. Since $W_{(z-1)}(\delta R)$ is minimized by taking the $z-1$ p^n terms equal to $\delta R/(z-1)$, minimizing W_z is equivalent to minimizing $(z-1)(\delta R/(z-1))^n + ((1-\delta)R)^n$. The minimum is attained for $\delta = (z-1)/z$, such that $p_{iz} = R/z$ for each i.
According to the principles of induction we have shown that W_z attains its minimum in $p_{iz} = R/z$, $i = 1, \ldots, z$, for all z. □

We now show that U^p as defined in equation 4 is minimized if the total weight that needs to pass through the directed bipartite network is evenly distributed.

Theorem 4.2: *Having to distribute a weight Δ over the arcs in a connected, directed bipartite network in which each node in set $\mathcal{M}$ has at least one incoming arc, and each node in set $\mathcal{P}$ has at least one outgoing arc, U^p as defined in equation (4) is minimized by distributing Δ over all arcs in the network evenly, regardless of whether the maximum matching or the greedy picking algorithm is applied.*

Proof: Define R as the total number of arcs in the network and define M as the number of arcs in the selection J. Note that $M = \max\{|\mathcal{P}|, |\mathcal{M}|\}$ and $R \geq \max\{|\mathcal{P}|, |\mathcal{M}|\}$. We have to distribute Δ over R arcs such that the U^p of the product-market network is minimized. Define $\hat{w} := \Delta/R$, i.e. the mean weight per arc. Since the greedy picking algorithm performs worse (lower or -at best- equal U^p) than the maximum matching algorithm, we can focus on the outcome for U^p when following the greedy picking algo-

rithm. So, for U^p, heavy arcs are picked before light arcs.
Suppose that there is an **uneven** distribution of this weight Δ (some arcs are heavier than $\hat{w} = \Delta/R$ and others are lighter) that has U^p value lower than the U^p in case of evenly distributed weights. We show that we can redistribute weight of arcs that are selected in the uneven distribution and thereby lower the U^p, which is a contradiction.
Suppose the greedy algorithm picks arcs $J = \{(i_1, j_1), \ldots, (i_M, j_M)\}$ with weights $w_1 \geq \ldots \geq w_M$. Define $\bar{w} = \sum_{j \in J} w_j / M$, i.e. the mean weight of the arcs picked. Note that $\bar{w}$ need not be equal to $\hat{w}$ since the greedy algorithm makes a particular selection out of all possible arcs.
Given the current selection of arcs J and their weights, we know from lemma 4.1 that U^p is minimized if all weights are even, i.e. if $w_r = \bar{w}$. This implies that all the arcs in the greedy selection J must have weight $\bar{w}$ otherwise our uneven distribution case cannot be the minimum; we would then be able to redistribute the weight over the arcs in the selection to produce a lower U^p value. This in turn implies that, since there is an uneven distribution of weights by assumption, there are arcs *not* in the greedy selection J that have weight *lower* than $\bar{w}$. After all, the weight of such an arc not in J cannot be higher than $\bar{w}$; the greedy algorithm would pick that heavier arc before any other for inclusion in J. This means that $\bar{w}$ is higher than $\hat{w}$. We can then remove $\bar{w} - \hat{w}$ from each arc in J, and redistribute that weight over the $R - M$ arcs not in J. This would lower the U^p of the current J. This is a contradiction as we assumed that our uneven distribution rendered the minimal U^p. An uneven distribution does not yield the selection J with the minimal U^p. □

Suppose there are $|\mathcal{P}|$ product classes and $|\mathcal{M}|$ market segments , with R arcs ($R \geq \max\{|\mathcal{P}|, |\mathcal{M}|\}$) in total and the total market size is D. The mean weight per arc is D/R, which is lower if R is larger. The maximum number of arcs possible in the bipartite network obviously is the complete network with $|\mathcal{P}||\mathcal{M}|$ arcs. So, in determining the minimum U^p, we have to look at the complete network.
We thus have the following corollary of theorem 4.2 that immediately gives U^*.

Corollary 4.3: *The term* $U^p = \sum_{(i,j) \in J} \frac{S_{ij}}{S_i} \left(\frac{S_{ij}^2}{D_j S_i} \right)^p$ *attains a minimum for a complete bipartite network with all arcs with weight* $D/(|\mathcal{P}||\mathcal{M}|)$. *This minimal* U^p *is:*

$$U^* := \sum_J \frac{D/(|\mathcal{P}||\mathcal{M}|)}{D} \left(\frac{(D/(|\mathcal{P}||\mathcal{M}|))^2}{|\mathcal{M}| D/(|\mathcal{P}||\mathcal{M}|) |\mathcal{P}| D/(|\mathcal{P}||\mathcal{M}|)} \right)^p = \frac{\min\{|\mathcal{P}|, |\mathcal{M}|\}}{(|\mathcal{P}||\mathcal{M}|)^{p+1}} \qquad (5)$$

The normalized parallelity thus is:

$$N^p = \frac{U^p - U^*}{1 - U^*} \qquad (6)$$

We now proceed by inspecting further properties of the (normalized) parallelity index. In Table 2, we see that parallelity is relatively low in all three examples on vergence given in Figure 3. From the fact that the parallelity value is the same for the divergent and convergent network, we see that parallelity does not pick up on vergence. The mixed network has low parallelity due to the cross-usage, i.e. product classes are not exclusively used by certain market segments.
The sensitivity of the parallelity measure is again inspected using the network depicted in Figure 4. In Figure 7, we have depicted the N^p for $p = 1.5$ for three values of γ (balancing the total demand over both segments) when using maximum matching. As

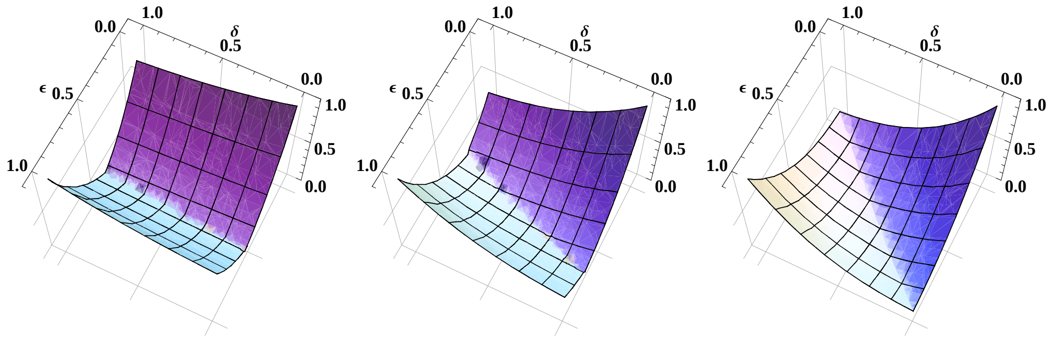


Figure 7. Plots of parallelity N^p for $p = 1.5$ for the network in Figure 4 for $\gamma = 0.1$ (left), $\gamma = 0.3$ (middle), $\gamma = 0.5$ (right) when using the maximum matching algorithm.

Table 2. Parallelity and Vergence with $p = 1.5$ and $\alpha = 3$ for the networks given in Figure 3

	Parallelity (max matching) N^p	Vergence $V^{\alpha p}$
Divergence network 3(a)	$\frac{\frac{10}{32}(\frac{1}{3})^p+\frac{2}{32}1^p)-2(\frac{1}{8})^{p+1}}{1-2(\frac{1}{8})^{p+1}} \approx 0.113$	-0.917
Convergent network 3(b)	$\frac{\frac{10}{32}(\frac{1}{3})^p+\frac{2}{32}1^p)-2(\frac{1}{8})^{p+1}}{1-2(\frac{1}{8})^{p+1}} \approx 0.113$	+0.917
Mixed network 3(c)	$\frac{\frac{10}{39}(\frac{10}{23}\frac{10}{18})^p+\frac{7}{39}(\frac{7}{16}\frac{7}{13})^p-2(\frac{1}{6})^{p+1}}{1-2(\frac{1}{6})^{p+1}} \approx 0.0289$	-0.142

expected, the measure is particularly sensitive for the loading to the largest market segment; if $\gamma \ll 0.5$, segment b is largest, so parallelity is particularly high if the load over both arcs into b is strongly asymmetric, i.e. if ε approaches either 1 or 0. If both segments are equally large, parallelity is high if the load over the pairs of arcs into both segments are strongly asymmetric, which is the case if both loading factors are either high or low. In a similar vein, parallelity is particularly low if the largest segment uses both products in equal shares, e.g. if $\gamma = 0.1$, parallelity indeed is particularly low at $\varepsilon \approx 0.5$. If both segments are equally large, parallelity is lowest if the segments use both products in equal quantities ($\delta \approx \epsilon \approx 0.5$), and if however one of loading factors is high or low, then the parallelity drops if the other loading factor causes divergence or convergence.

All in all, we see that, unlike vergence, normalized parallelity picks up on the extent to which there is cross-usage or exclusive usage of products, while parallelity is not informative about vergence. Vergence and parallelity hence are largely complementary. We thereby have to reflect on both vergence and parallelity to capture important information on the network structure that we would miss if we would use only one index.

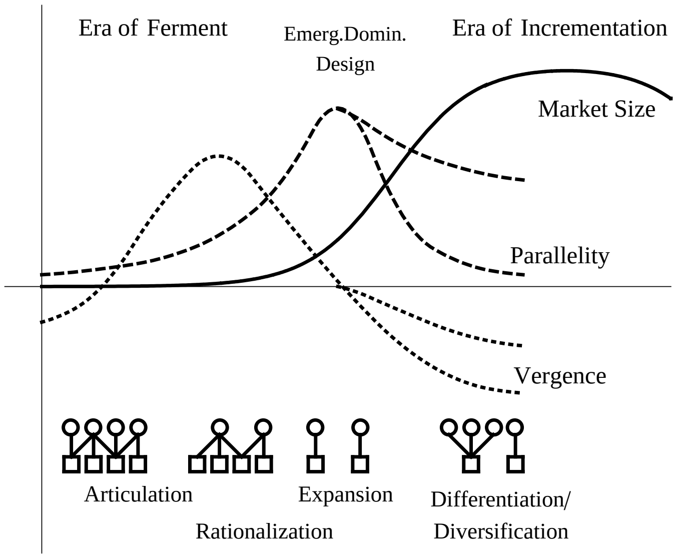


Figure 8. Impressions of the product-market network over the product life-cycle, and the parallelity and vergence values expected

5. Product Selection and (Re)Design Guidelines over the Product Life-Cycle

As entry prior to coalescence of the dominant design considerably increases chances of survival (Suárez and Utterback 1995, Klepper and Simons 2005, Christensen *et al.* 1998, Agarwal 1997), it is likely firms will want some experimental products in their portfolio. However, firms then have to cope with shocks to technology to master, markets to target and competition to beat. Dynamic efficiency of any focal firm is then higher when taking into account (the likelihood of) such events in product selection and (re)design.
In section 4, we provided two indices that quantify the product-market network features and thus conveys information on the product life-cycle phase and thereby pending changes to the industry state. In this section, as explained in section 3, we resort to speculation on the development of vergence and parallelity over the life-cycle. We stress that with suitably rich historical data available at the appropriate level of aggregation, it is easy to verify and test our claims on the -arguably well-behaved (see Figure 8)- development of the parallelity and vergence values.
Our concern in the present section is with the product design guidelines and how these relate to the measured values of vergence and parallelity, *ex ante*. For each of the phases and the actual dominant design emergence, we reflect on the meso-level evolution of the industry and concerns of the individual firm, and how this translates into (recommended) activities and strategies to be employed by the marketing and product engineering departments engaged in selecting and (re)formulating the product design.

5.1. *Era of Ferment*

Following a 'radical advance', the era of ferment is characterized by firms struggling in absorbing or destroying the innovative technology, thus giving rise to high variation in (product) technology and a range of new market opportunities (Anderson and Tushman 1990). Apart from the occasional starter dedicating itself to narrow envisioned segments (see Macdonald 1985), we focus on 'prospector' firms (Walker and Ruekert 1987) that aspire to become large, dominant players (see Macdonald 1985). Given the high uncertainty, such firms keep open market options and target various, yet vaguely defined segments. We therefore expect moderate to low parallelity in the meso-level product-market network.

Firms find themselves in a catch-22 situation of waiting for more articulated preferences on what to make, but receiving none because consumers need a product to reflect on. Firms can bootstrap out of this by pushing experimental proof-of-concept products out onto the market broadly and setting up transparent channels to compile a list of desirable service characteristics and to thereby obtain preliminary definitions of market segments to target. By doing so, the perception of the market segments becomes more clear, and -as consumers build experience- also more defined. During this 'articulation' process, in which marketing plays a prominent role, the design adage hence is 'keep technical options open, push experiments broadly to gather and breed consumer preferences, isolate segments to target'. Empirical evidence indeed reveals that firms that remain diversified at this stage have a lower hazard rate due to the innovation information economies (Agarwal 1997).

Due to this articulation, firms uncover and target the larger market segments. We presume, not unrealistically, that the same service characteristics can be met with different product technologies, so, at least at meso-level, the variety in core technologies used remains high. Few segments and many products reflects in convergence in the product-market network.

Waiting for sufficiently articulated preferences is paramount. Given the fluidity of the product-market network, technological and contractual lock-in, dead-end research and equipment write-offs loom. Furthermore, Christensen *et al.* (1998) hint that early entrants, or rather firms with a premature dedication to certain product technology, build competences that form a competitive liability due to corporate inertia later.

However, with the gradually more articulated preferences, less risk is involved in narrowing down on the technical options kept open previously. As convergence in the product-market network at industry level is economically inefficient, this inevitably backfires in financial performance of individual firms. The implicit process is that regular economic drivers render selection of more profitable technology. The explicit process is to have engineering backtrack service characteristics to technical solutions. This might require an unsentimental switch to competing technology.

During this 'rationalization' process, the design adagio is to 'prune and select technical options'. Due to the prior articulation, the set of technologies has already been conditioned on commercial viability[1]. So, certain product classes are deselected from these convergent subnetworks and hence the product-market network gets higher parallelity (more dedication).

[1]Due to context insensitivity of new product development procedures, project cancellation criteria necessarily cover the whole range of issues like presence of competition, potential market preferences, regulations, et cetera (see Balachandra 1984)

5.2. *Dominant Design Emergence*

After articulation and rationalization, each of the generalist firms[2] envisions that the product-market combination it targets is a potential dominant design. Well-known extreme cases of entrenched competition of such 'potential winners' are the Betamax, VHS and Video2000 and the DVD+R, DVD-R and DVD-RAM format wars. Under positive scale advantages accruing to both the producer as well as consumer, firms are engaged in a 'race of product classes' to reach a critical scale beyond which the market tips. Firms are now faced with a dilemma: risk doing an irreversible investment in upscaling production to try tipping the market by exploiting scale advantages or risk waiting for clear market signals while others might tip the market to their advantage in the meantime.
Indeed, it is crucial for marketing to closely monitor sales figures of all firms in the industry. If marketing sees that the product sold loses market share despite repeated attempts to further diffusion, remaining options are to phase out or jump the bandwagon of whatever is emerging as dominant design. In the latter case, the engineering department is commanded to switch to producing that design. Firms that fail to tip the market and adopt the dominant design too late (so fail to grow a significant market share), are forced into demise in the industry shakeout. From empirical findings, Christensen *et al.* (1998) recommend to monitor for 'convergence' in the product-market combination (indeed, high parallelity) and to rapidly adopt the dominant design to drastically lower the hazard rate.
Despite this waiting, industries generally do not end up in a deadlock due to great heterogeneity in information, beliefs, risk aversion, product portfolios and endowments. Due to this, some firms make arrangements to upscale production and kick off an aggressive marketing campaign in an ultimate attempt to conquer the market. Not only should firms expand the market share fast to win the *within* product-market competition, but there is a *between* product-market competition externality as well; head-on competitors have shared interests in having their (shared) design to emerge as dominant. Not surprisingly, in this phase, head-on competitors team up in alliances as with the DVD+R consortium or deploy a large production base as with licensing VHS technology.
Under the presumption that 'articulation' and 'rationalization' has made our focal firm convinced of its product-market choice, it proceeds with an 'expansion' process in which the design adagio is to 'standardize, upscale and market aggressively, and -if monitoring by marketing indicates it is necessary- switch promptly'. Indeed, prospector firms focus on aggressive advertising and promotion by marketing and provision of competitive products by engineering (Walker and Ruekert 1987, Macdonald 1985). Production moves from a make-to-order to standardized mass-manufacturing system

At the meso-level, we see that not only will diffusion in the consumer population run in favor of the already more popular product; there is preferential attachment on the producer side as well. After the shakeout, only one or at best a few product-market combinations survive, thus giving rise to a highly parallel, neutrally vergent network.

5.3. *Era of Incremental Change*

With the emergence of the dominant design, the basic product technology is fixed. Entrants best conform to the basic architecture (Christensen *et al.* 1998). Subsequent innovations are incremental and quickly depleting the set of economically viable technological

[2]As opposed to specialists that possibly deliberately target specific niches too little or too distinct to be considered or even examined by players aiming for the large majority of customers (see e.g. Macdonald 1985).

opportunities. Firms generally target the market majority and their products are close substitutes, as such bringing about price margin erosion. The basic competitive strategies now are: price-fighting, differentiation/ specialization (for an introduction, see Porter 1980)[1] and we add diversification to that.

In diversification, engineering tries to cut marginal costs, typically by increasing scale and efficiency of internal operations, while marketing is on the look-out for options to squeeze additional willingness-to-pay by tailoring features into the existing product. Indeed, marketing and engineering are engaged in balancing marginal benefits of diversification/ dedication and marginal cost savings of standardization and commonality. Where marketing is lobbying for internal divergence to attune service characteristics to individual consumer needs, product engineering is interested in moving these decoupling nodes further down the production process and the bill-of-material. In (re)designing the product family (based on the dominant platform design), marketing should be involved in deciding on which components to standardize and placing decoupling points, so as not to preclude (future) diversification options. Note that such micro-level divergence ultimately reflects in divergence at industry level.

Marketing might even be on the look-out for commercially viable options to differentiate so as to avoid generalist competition. Product engineers should indicate possibilities for and technical feasibility of proposals for differentiation. To provide a genuinely different product, it is very likely to be necessary to provide specialized components, and to, thereby, employ (moderately) distinct product technology. At the industry level, this differentiation increases parallelity in the product-market network.

Within each individual firm, marketing and engineering need to interactively scan for both commercially and technically viable means to diversify and differentiate, and then, together, adjust the technical specifications to meet alternative service characteristics. Marketing has an important role in assessing differential advantage (Walker and Ruekert 1987). We phrase the recommended guideline as 'interactive scanning and positioning'.

When competing just on price, production scale and internal efficiency is crucial, so priorities are set by engineering (Walker and Ruekert 1987). With an increase in size of firms, their product-market choice will contribute more to the indices, so bring about a marginal increase in parallelity and marginal regression to neutral vergence.

5.4. *Overview*

In Figure 8, we plot an impression of the product-market networks and the stylized parallelity and vergence values over the life-cycle phases. Firms should seek articulation until vergence peaks, then seek rationalization until parallelity peaks and then rapidly expand until after the shakeout, to then follow a diversifying, differentiation or price-fighter strategy.

We also saw that both the marketing and the engineering department have their distinct role in each of the industry life-cycle phases. During the articulation process, engineering is experimenting, while marketing is the focusing instrument. During the rationalization process, marketing guards service characteristics, while engineering prunes options. During expansion, marketing and engineering are engaged in a concerted advertising and upscaling. During the era of incremental change, marketing and engineering are

[1]We refrain from strategy recommendation; particularities of the firms and industry are required for that, e.g. with many price-fighters, differentiation might be recommendable, while with many diversificators, differentiation to serve a single thick niche might be recommendable, et cetera.

Table 3. Meso-level developments and restructuring guidelines over the industry life-cycle

	Meso-level developments in product-market network	Product selection and design guidelines for individual firm
Era of Ferment	From neutral vergence and low parallelity into convergence	Articulation: 'Keep technical options open, push experiments, collect preferences to focus'
	From convergence to neutral vergence and high parallelity	Rationalization: 'Select and prune technical options'
Design emergence	Increasing parallelity	Expansion: 'Standardize and expand, if necessary switch promptly'
Era of Incremental Change	Increasing divergence, decreasing paralellity	Diversification: 'Scanning and positioning'
	Increasing parallelity	Differentiation: 'Scanning and positioning'
	Increasing parallelity and regression to neutral vergence	Price: 'Scale'

engaged in a joint effort of scanning the market and technical options in the classical trade-off between meeting all customer requirements and operational performance in production.
In Table 3, we list, per life-cycle phase, the processes the firms are involved in, the development of the measured parallelity and vergence values due to that and the recommended product design activities to increase the chances of survival. We hereby provide a dynamic 'theory' of business strategy sought after by e.g. Porter (1991).

Two remarks about the procedure thus proposed. The first remark is about the interference with the causality. The supposed meso-level developments are due to assumed firm behavior. From these meso-level developments, we in turn derived recommendations for a forward-looking strategy. This in part fulfills the propositions about the development and in part alters the reality dealing with. As such, strategies that anticipate 'otherwise regular developments' settle in practice and thereby create an alternative reality to subsequently deal with. This also reflects in future strategies. We stress that such phenomena are common in social and organization sciences.
The second remark is about the availability and suitability of data. For an individual firm to derive recommended product selection and design guidelines, it should follow the method described in section 3. From the operational definitions provided in the section 4, we see that the indices are not particularly data hungry. During expansion and the mature phase of the industry, regular market analysis (through surveys) and common reverse engineering allows demarcating market segments and product classes. However, data is scarce at the onset of an industry; customer requirements are yet to be articulated. Luckily, the indices are -due to the weighing- primarily sensitive to sales data of the biggest players (and these players are arguably most important for the course of industry developments in the end, see Agarwal 1997). Due to their commercial concerns, such players are necessarily visible. Regular market surveys among customers and engineering studies of products available would still allow establishing an accurate approximation of the product-market network.

6. Conclusion

Any firm is wound up in a recurrent deciding what to make for who and how. Although 'incorporating market concerns' is explicitly on the agenda in both marketing and operations management literature on product-market selection, the market is generally taken to consist of well-demarcated segments with static demand figures, and changes therein (implicitly) taken to simply require a rerun of the same algorithms. To us, this is a serious underestimation of how uncertainty and anticipated developments, notably shocks to the market caused by technological change and competition, weigh in such investment decisions. We stress that truly looking forward requires transcending the micro-level to a meso-level focus, and notably taking into account the product life-cycle pattern. Aiming for quantitative triggers for product selection and (re)design guidelines, we introduced the notion of the meso-level product-market network and introduced two operational measures for critical dimensions of that network. We subsequently argued that these two measures do indicate the transition from articulation to rationalization phases and the emergence of the dominant design. We also argued that they uncover the prevalent product positioning strategy (cost-based, differentiation or diversification) in the era of incremental change. Our findings are concisely depicted in Figure 8.

We arrive at the claims contained in Table 3 on *meso-level* developments and the recommended *micro-level*, forward-looking product selection and (re)design guidelines. We uncovered the distinct roles of both marketing and engineering departments in each of the industry life-cycle phases. We thereby refined the classical trade-off between customer utility and operational performance.

In line with the method formulated in section 3 to validate and calibrate the look-up table instrument, an obvious future research agenda is to empirically establish the vergence and parallelity curves by collecting longitudinal sales data of multiple industries. In-depth interviews with professional marketing and engineering employees should then help to partition the market into segments and products into classes in the various cross-sectional point-in-time. More elaborate literature studies and interviews with business strategists should further confirm the product redesign guidelines we isolated.

On the technical side, we have shown that with the largely complementary vergence and parallelity indices, we cover the fundamental properties of the product-market network structure. Despite a certain drop in informational value upon further aggregation, it is worth investigating extension of the indices to multiple technical product characteristics.

We reiterate that our indices can be used for other weighed bipartite networks as well, e.g. product class and component type networks, or buyer and supplier networks, but with different interpretations, naturally. Our indices possibly even have less obvious uses like quantify dimensions of diversity (see e.g. Stirling 2007).

Future research should assess the value of other indices for our purpose. Frenken (2006), for instance, uses entropy to convey information on technological diversity over the product life-cycle, albeit at a macro-level and where market segmentation reflects only implicitly in quantified, apparent insubstitutabilities.

Finally, we are interested to learn whether the indices are usable in business practice, and the value of our recommended guidelines at the various points.

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