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Perspectives and Misconceptions about Frugal Engineering in Advanced Product Development: An Industry Insight

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**Technology and
Innovation Management**
at Hamburg University
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Perspectives and Misconceptions about Frugal Engineering in Advanced Product Development: An Industry Insight

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Abstract

Frugal innovation and frugal engineering are becoming increasingly important in both academic and practical discussions in the face of various economic, social and environmental pressures. Despite numerous positive associations and opportunities of frugality in the corporate environment, the discourse is still characterized by several barriers and enablers that impede a broad diffusion. In our paper, we contrast these barriers and enablers using a mix of industry evidence from action research and interview studies. In doing so, we highlight common misconceptions in the conceptual understanding of frugal engineering and create new perspectives on frugal product development specifically for practitioners in the field.

1 Introduction

Given the global challenges the world is currently facing, a radical transformation is needed to address the increasing environmental pressures and the cost of living crisis (IMF, 2022; Achteplik et al., 2024). Due to its high relevance in both advanced and emerging economies, this paper discusses the growing research field of frugal innovation and frugal engineering as new perspectives to address the changing socio-economic dynamics (Brem, 2017; Herstatt and Tiwari, 2020; Tiwari and Herstatt, 2020).

1.1 Frugality and “Over-Engineering”

Frugal innovation have become increasingly popular in innovation research over the past decade and are studied from a variety of different perspectives (Hossain et al., 2022). Frugal outcomes emphasize the affordability of a product or service while maintaining technological excellence with the fulfillment of core functionalities as well as an optimized technological and customer-related performance level (Weyrauch and Herstatt, 2016; Winkler et al., 2019). Given the sufficiency-oriented “doing more with less for more” character of frugal innovation (Radjou and Prabhu, 2015), a growing number of scholars further discuss their relation to (corporate) sustainability (Rosca et al., 2017; Albert, 2019; Achteplik et al., 2022; Dima, 2022; Le Bas, 2023).

The origins of the discourse on frugal innovation can be found in emerging economies which are typically characterized by scarcity of resources and poor infrastructures. Scholars note that under these often-severe conditions, so-called “good-enough” innovations frequently achieve significant commercial success (Govindarajan and Trimble, 2012; Radjou and Prabhu, 2015; Asakawa et al., 2019). In this way, multinational companies (MNCs) can gain a competitive edge by offering appropriate and less sophisticated solutions for customers that are normally overlooked by their established innovation paradigms (Prahalad and Lieberthal, 1998; Prahalad and Mashelkar 2010). Particularly technology-leading incumbent firms often follow a *sustaining innovation trajectory* and thus prefer those innovations that drive already sophisticated products into ever higher and over-engineered performance levels (Christensen and Bower, 1996; Christensen, 2016).

Contrary to frugal innovations, these conventional outcomes are increasingly perceived as being “inadequately engineered” and “too-good-to-succeed” (Tiwari and Herstatt, 2013). In view of the increasing need for sufficiency and emerging social trends in favor of “voluntary simplicity” and “frugality-by-choice”, frugal innovation and frugal engineering represent a promising strategy

especially for advanced, resource-intensive product development (Bocken and Short, 2016; Tiwari and Herstatt, 2020; Rebouças and Soares, 2021; Bianchi and Cordella, 2023).

1.2 Empirical Perspectives on Frugal Innovation and Research Aim

Existing research on frugality in innovation management highlights its fundamental importance in achieving the widely recognized triple bottom line of social, environmental, and economic sustainability (Herstatt and Tiwari, 2020; Achtelik et al., 2022; Le Bas, 2023). Thus, especially MNCs can leverage frugality to enhance their overall sustainability orientation in a comprehensive manner. Not surprisingly, scholars regard frugality as a potential future *megatrend* for societies and businesses alike (Brem, 2017; Le Bas, 2020; Tiwari and Herstatt, 2020; Le Bas, 2023).

On the other hand, there is also a vast body of literature on potential barriers that hinder a rapid integration of frugality into the corporate landscape. Prominent examples are cultural issues within product development, fear of cannibalization and competition, concerns regarding image losses, or missing low-end innovation capabilities (Agnihotri 2015, Radjou and Prabhu, 2015; Reinhardt et al. 2018; Niroumand et al., 2021; Krohn, 2022).

Further, we observe a dearth of empirical research and detailed case studies about frugal product development in Western MNCs (rare exceptions are, among others, Weyrauch et al. (2021), Krohn (2022) or Achtelik et al. (2023)). In particular, there is an increasing demand for empirical insights into how frugal engineering is generally perceived by the industry – especially among companies that are not directly involved in developing frugal products and are confronted with the promising potential of a frugal approach to product development.

Consequently, the three research questions dealt with in this study are: (1) *How is frugality perceived in the industry?* (2) *What debates about its implementation can be observed in practice?* (3) *In how far does frugal engineering represent a promising alternative for potentially inefficient innovation trajectories that continuously aim for performance maximization?*

To answer these questions, we draw on a wide range of empirical findings and observations from the past few years, obtained through action research, trade fair visits and presentations, as well as numerous student projects. In our working paper, we provide initial answers and demonstrate that the individual barriers and enablers of frugality should not be discussed in isolation. Instead, under the premise of holistic sustainability, they should be integrated into an overall entrepreneurial discourse that emphasizes a subtle paradigm shift in the industry towards more “affordable sustainable excellence” (Brem 2017; Le Bas, 2020, 2023, Tiwari, forthcoming).

In this way, we introduce frugality as an overarching *innovation paradigm* that seeks to *optimize* expensive, complex, and often over-engineered products to a more adequate level by means of reduction and sufficiency. As will be shown, we introduce a novel perspective on common misconceptions about frugal engineering and the contradictory character of individual enablers to their related barriers.

The remainder of this paper is structured as follows. Chapter 2 provides a detailed overview of the research landscape of frugal innovation with an explicit emphasis on business barriers and enablers. Chapter 3 shortly presents our research methodology and the integration of empirical data into the theoretical abstraction process. Chapter 4 connects the academic discourse with our findings and juxtaposes individual barriers and enablers to gain a fresh perspective and clarify common misconceptions within the industry. Chapter 5 summarizes our working paper.

2 Theoretical Background

2.1 A Short of Overview of Frugal Innovation Research

Initially, the term “frugal innovation” was coined by the well-known business magazine *The Economist* in 2010 to describe good-enough innovations tailored to the needs of cost-sensitive customer segments with respect to price and functionality. The authors report that product developers in emerging markets foster affordability and simplification by eliminating premium features without negatively affecting the quality at all. Radjou and Prabhu (2015) delineate this observation as the creation of more value with constrained resources, often denoted as “doing more with less”. Hereby, developing a mindset that regards the inadequacy of resources as an opportunity for growth rather than a limitation is imperative (Radjou and Prabhu, 2015; Krohn and Herstatt, 2018; Asakawa et al., 2019).

According to Basu et al. (2013), there are four factors that distinguish frugal innovations from other types of innovations, i.e., the driver, the method, the required core capabilities, and the location of the invention. Thus, frugal innovations are motivated by the actual *needs* of the customers in contrast to innovations which mainly focus on the *desires* of the customers. Similarly, Hossain et al. (2022) describe antecedents of frugal innovations that – besides business opportunities –encompass mainly socially related needs to improve living standards or environmental sustainability.

More specifically, the literature is largely consistent with three decisive criteria of a frugal product, namely a significant cost minimization, focus on the basic functionalities as well as an optimal degree of performance (Weyrauch and Herstatt, 2016). Other characteristics attributed to frugal innovations encompass robustness, user-friendliness, ease of use, high value and quality, scalability, the reduction of the use of materials, and last but not least, sustainability (Rao, 2013; Weyrauch and Herstatt, 2016). Compared to other types of resource-constrained innovations, Zeschky et al. (2014) emphasize a higher technical as well as market novelty of frugal products and services.

Recently, frugal innovations are often depicted as a multidimensional process rather than merely an outcome, signifying a frugal mindset as a requirement for a frugal process, which may finally result in a frugal product (Soni and Krishnan, 2014; Krohn, 2022). In this regard, Knizkov and Arlinghaus (2020) indicate that frugal processes do not necessarily have to result in frugal products. However, frugal products call for the frugality of all processes preceding them (Soni and Krishnan, 2014; Knizkov and Arlinghaus, 2020). In this context, scholars also increasingly discuss the term *frugal engineering* as the processes, methods, and paradigms that embody the idea of frugality and thus may result in a frugal outcome (Soni and Krishnan, 2014; Beise-Zee et al., 2021; Achtelik et al., 2023).

On a broader level, Le Bas states that a frugal innovation “does not shape one innovation as another. It relies on a new engine (paradigm) to produce new technological knowledge” (2020, p. 80). This paradigmatic perspective contributes to a wider understanding of frugality in innovation management and thereby supports the debate to shift away from specific outcome-oriented frameworks. Thus, frugality may be understood as a high-level strategy and perspective that serves a deeper entrepreneurial and social purpose, such as corporate sustainability (Herstatt and Tiwari, 2020; Achtelik et al., 2022). For instance, Herstatt and Tiwari see that the “overlap of frugal innovations with the principles of circular economy could act as a driver for the latter, and environmental sustainability can only be achieved when it is married to the concept of frugality” (2020, p. 28). Likewise, Achtelik et al. (2023) regard the radical reorientation necessary for frugal engineering as an important enabler towards more adequately and eco-friendly designed products without unnecessary over-performance.

2.2 Business Enablers of Frugal Innovation and Engineering

Although the growing relevance of frugal innovations is conspicuous, the research to date has somewhat neglected to adequately address the enablers and barriers to their implementation in *advanced* economies. Consequently, this gives rise to a comprehensive empirical study delving into the potential of the application of frugal innovations on a larger scale in Western countries.

While advanced economies have been growing at a slower pace, emerging economies like India and China have been swiftly evolving. This trend demonstrates the importance of establishing a strong market position in developing economies to maintain a solid presence in developed countries as well, considering the dynamic nature of the market nowadays (Immelt et al., 2009). Prahalad and Hart (2002) ascertain that a reassessment of the price-performance ratio of products along with the adoption of new technologies and business models are imperative for the success of multinational companies. Likewise, Tiwari and Herstatt (2014) suggest that new and improved R&D are crucial for successfully tapping in the bottom of the pyramid (BOP) market and addressing the needs of the price-sensitive customer segment through frugal innovation.

Additionally, the adoption of frugal innovation contributes to the growth of MNCs owing to the high volumes of the local emerging markets despite their insufficient resources (Tiwari and Herstatt, 2013). Immelt et al. (2009) attribute pioneering novel applications for products, catering to new customer segments at a lower price point, having a competitive edge, and opening a new market in developed markets to frugal innovation. All of the above requires the presence of a frugal culture in MNCs and a deep understanding of the local needs of such markets (Agnihotri, 2014).

As stated, frugal innovation eliminates avoidable and unnecessary complexity, as it often – though not always – depends on basic engineering skills (cf., e.g., Tiwari and Herstatt, 2014). Changes in the design of premium products, e.g., the elimination of certain high-end features that are deemed unnecessary for the emerging market, can result in lowering the price-performance ratio, furthering frugal innovation in MNCs. As per Tiwari, Fischer and Kalogerakis (2016) the integration of user-friendly features and the ease of use of frugal products create social value for emerging markets in addition to reducing production complexity and shaping new paths for economic prosperity.

The collaboration of MNCs with local companies in emerging markets can be advantageous for the innovation of frugal products as it eases access to geographically remote developing markets along with fostering the deployment of the concept of frugality and its commercialization (Agarwal and Brem, 2012). Considering the scarcity of resources in emerging markets, it is essential to find smarter approaches and appoint local workforce with firsthand experience in tackling the prevalent issues of such markets into the R&D teams in MNCs for the sake of knowledge transfer (Zeschky et al., 2011). It is crucial to keep track of, learn from, and adopt the innovations released by other local as well as MNCs in order to keep a leading market position. The importance of training the users of the innovations and monitoring customer satisfaction levels is also stressed (Immelt et al., 2009).

In the literature, top management support is highlighted as a critical enabler of frugal innovation. The high influence of top management support on the promotion of frugality is underlined in many papers (Ramdorai and Herstatt, 2015; Krohn and Herstatt, 2018; Niroumand et al., 2021). The ability to correctly determine limitations in existing projects and substitute them for frugal activities with enhanced future prospects is pivotal for the profitability of MNCs. Niroumand et al. (2021) also spotlight the vitality of possessing managerial qualities such as the correct identification and utilization of business ventures with the potential to create value.

Evidently, there has been an increasing pressure with regard to sustainability in recent years. Numerous researchers elaborate on the role that frugal innovation can play in fostering sustainable development. Frugal innovation is highly correlated with low material consumption, a decrease in the use of natural and financial resources, the minimization of depreciating resources, such as energy, and a reduction in production time (Radjou and Prabhu, 2013; Rosca et al., 2017; Albert, 2019).

2.3 Business Barriers of Frugal Innovation and Engineering

In the literature, several barriers have been identified as a cause for the impediment of the expansion of frugality on a large scale in the West. Krohn (2022) determines premium innovation biases as a barrier that arises from a policy that relies heavily on high-end solutions, causing a negative behavioral intention, hampering all attempts to integrate frugality into the company's value chain. With the main focus of MNCs lying on high-end products, it is challenging for them to employ a low-cost approach due to the constraints associated with it. By virtue of being trapped in the loop of path-dependent processes and conforming to the same strategic goals, strategic path dependencies limit MNCs' flexibility and scope for action. Consequently, flexible strategic adjustments are obstructed, creating a bridge between the company's objectives and the current market conditions.

Similarly, the lack of a frugal mindset within Western enterprises is discussed by many researchers (e.g., Radjou and Prabhu, 2013; Agnihotri, 2014). For instance, Reinhardt et al. (2017) stress the fact that managers in MNCs are more likely to unconsciously favor and invest in premium products over low-cost ones as a result of the high-end bias they hold, associating high-end innovations with more potential and underestimating the purchasing power of the cost-sensitive segment. An absence of the ambidextrous capability to manage both high-end and low-end products depicts a restriction for the development of frugal projects in MNCs (Reinhardt et al., 2017; Krohn et al., 2020).

Despite the expansive know-how that MNCs possess, firms face challenges—both technical and organizational—when it comes to developing frugal products that are aimed at emerging markets due to their unfamiliarity with effective methods to tackle the needs of the BOP markets (Radjou and Prabhu, 2015). Given the particularity of the market needs in emerging countries, local companies appear to be best suited for developing proper solutions due to their intertwined relation to the respective market. The inability of R&D departments within multinational organizations to comprehend the necessary means to effectively approach the local market needs of the cost-sensitive segment jeopardizes the success of frugal innovation in MNCs (Altmann and Engberg, 2016).

A critical barrier regarding the implementation of frugal innovation in MNCs is the fear of self-cannibalization. As per Angot and Plé (2015), MNCs believe that launching frugal products into the same markets where the high-end products of the company are sold may pose a threat to the profitability of the company as the company would be competing with itself. Existing high-end offerings may be neglected if the customers in the target markets predominantly opt for frugal products.

Another key concern is the risk of a cost-quality trade-off. It is a widely held view that compromising on quality in favor of price reduction is likely a prerequisite for developing frugal innovations (Karnani, 2007). The development of frugal products may be perceived as a degeneration in value proposition as a result of the minimalization of financial resources, and hence features. As opposed to emerging markets where frugality leads to an upgrade in quality, consumers in the West tend to have a negative perception considering the frugal elements and interpret them as a downgrade compared to the premium products they are acclimated to (Angot and Plé, 2015). Angot and Plé (2015) also maintain that

frugal innovations are susceptible to cease to be attractive for BOP customers as their economic situation ameliorates and they no longer feel obligated to buy low-end products.

Challenges accompanying overestimations of the cost-sensitive customer segment's real purchasing power, disparities between the price-performance paradigm and incongruities between the structure of the organization and the characteristics of the market coupled with the weak infrastructure in the developing countries portray further common impediments that MNCs face (Karnani, 2007; Immelt, et al., 2009). Profitability depicts a substantial barrier to the application of frugality in MNCs. Many researchers claim that the small size of the BOP market reflects negatively on revenue generation in MNCs (Karnani, 2007; Christensen, 2016).

Economies of scale are another major problem raised by many in the literature (Wohlfart et al., 2016; Rosca et al., 2017). Scholars argue that multinational companies consider the development and diffusion of frugal innovations targeting low-income markets as an intricate endeavor, which is why they are reluctant to apply them. In addition, the marketing and distribution of frugal products are closely linked to elevated costs in view of the geographical as well as cultural dissemination of the rural poor, which depicts an inhibitor for scalability. Scalability is also hampered by the weak infrastructure in the aforementioned economies.

Karnani takes the view that innovations intended for BOP markets are accentuated by "much hyperbole. The fortune and glory at the bottom of the pyramid is a mirage" (2007, p. 108). Owing to the high required expenses and low lucrateness, MNCs gain no competitive advantage (Karnani, 2007). Angot and Plé (2015) assert that the above-mentioned reasons induce insufficient top management support, which constitutes a huge impeding factor for the implementation of the concept.

Another key limitation concerning the utilization of BOP business models in developed countries is that the Western perception of innovation differs substantially from the fundamental premise of frugal innovation – doing more with less – alluding to creating more value with more constraints and fewer resources (Angot and Plé, 2015). MNCs gravitate toward radical innovation and have a propensity for over-engineering products, e.g., by incorporating more features and resources with every innovation.

Further, potential economic regulations are clearly highlighted as a major hurdle for Western companies. They possess a deficient understanding of the customers, licenses, approvals, intellectual property rights, and guidelines imposed by the governmental institutions in emerging countries, which tend to be more stringent than in developed countries, not to mention, the additional difficulty of innovating under resource and budgetary restrictions and underdeveloped infrastructure (Ahuja and Chan, 2014; Angot and Plé, 2015).

In terms of developing solutions specifically for the poor, the implementation of frugal innovations may spark ethical controversy attributed to the protection of the impoverished (Angot and Plé, 2015). As explained by Karnani (2007), the poor lack the necessary awareness and education to determine the actual value of products, and therefore, are prone to fall victim to the unfavorable offerings that MNCs tailor to them due to their low prices. What is more, he criticizes the application of the frugal phenomenon by MNCs and refers to it as a "dangerous delusion" and "exploitation of the poor". On another note, the suppression of local enterprises by MNCs embodies another serious ethical concern. By adopting frugal solutions, MNCs obstruct the evolution of local suppliers who deliver not only economic but also social contributions to their communities. One criticism of much of the literature is that MNCs often neglect social value creation as a consequence of relying heavily on creating economic value (Karnani, 2007; Angot and Plé, 2015).

3 Methodology and Theoretical Abstraction

As shown in Table 1 we build our research on a variety of primary data sources that we have obtained through different methodologies. The primary aim of these research projects was to promote the concept of frugal engineering and simultaneously investigate crucial enablers and barriers in implementing a “subtractive thinking” in organizations.

- **Action research:** Through a three-year action research project we investigated the phenomenon of over-engineering in the material engineering department of a leading German automotive manufacturer. We evaluated the potential of frugal engineering to foster the implementation of adequately engineered, price-efficient and more sustainable, secondary materials. Hereby, we drew our research and the associated organizational invention as part of action research on qualitative data, such as interviews and observations.
- **Observations:** Across the past years, we took part at several presentations and press conferences at leading trade fairs in the automotive plastic sector presenting the promising potential of frugal engineering for the industry. Simultaneously, we adopted a nonparticipant observer role in a plethora of discussions with industry experts.
- **Interview Case Study #1:** Our first case study was conducted in a leading Dutch Healthcare company with expert interviews held in Germany and India. In particular, we were interested in the awareness, diffusion and potential barriers of frugal innovations in the high-tech medical sector. In a similar vein, we specifically asked for the perception and experiences made with frugal products and the impact on corporate sustainability.
- **Interview Case Study #2:** In our second interview case study we connected the dots in the highly emerging yet underresearched industry of 3D-printing. Although large diffusion is still lacking and engineering processes might be complex, the related product outcome share a lot of similarities with the idea of frugality. By interviewing leading industry experts and researchers we gained valuable insights into the recognition and acceptance of frugal engineering in this industry.

Table 1: Overview of primary data sources

Methodology	Industry	Data Sources
Action research	Automotive	Expert interviews (n=71) Focus group interviews (n=3) Workshops (n=5) Observations (across three years)
Observation (nonparticipant observer role)	Automotive, polymer industry	Presentations at trade fairs with corresponding discussions (n=5) and observations (across two years)
Interview Case Study #1	Healthcare	Expert Interviews in Germany (n=16) and India (n=4)
Interview Case Study #2	3D printing industry	Expert Interviews (n=9)

As part of the theoretical abstraction process, we analyzed the data using a common two step deductive-inductive coding procedure (Kuckhartz, 2018).

First, we assort our data into predefined groups called “frugal engineering barriers” and “frugal engineering enablers”, respectively. In a second step we inductively generated thematic sub-categories for the individual barriers and enablers. The result of this coding process is shown in Table 2 and paved the way for the subsequent discussion in Chapter 4. Through this thematic juxtaposition of the individual barriers and enablers we derive “*balanced perspectives*” on frugal engineering and defused some of the misconceptions prevalent in the industry. An illustrative summary of the research process is shown in Figure 1.

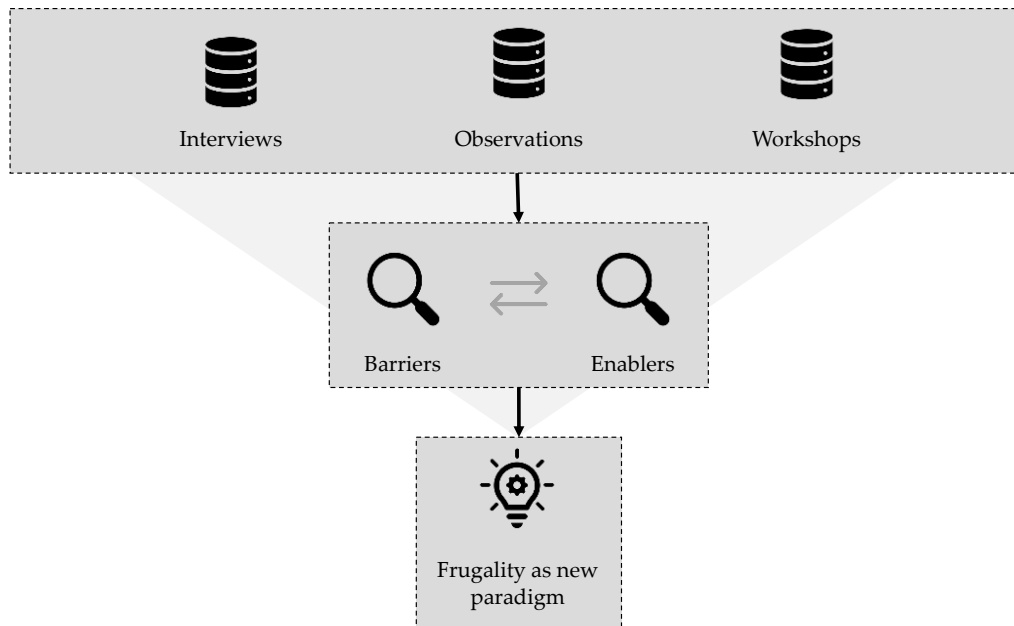


Figure 1: Overview of research process [own illustration]

4 Findings and Discussion

4.1 The Contradictory Character of Frugality in Product Development

As confirmed in a plethora of industry contacts with managers and experts, companies face a variety of opposing enablers and barriers when it comes to frugality. Relating the aspects discussed in the literature and presented in section 1.2 and 1.3, frugal innovations present both growth opportunities and risks; they seem more appropriate for one group of customers but appear “cheap” from a different customer perspective. Frugal innovations may result in radical breakthroughs (Immelt et al., 2009; Ramdorai and Herstatt, 2015; Weyrauch et al., 2021), at the same time, they may be perceived as just an approach for incremental cost improvements of already existing products.

Our research has shown that an isolated discussion of frugality barriers is not supportive, as the existence of prevailing *performance-improving paradigms* often leads to dogmatic statements such as “reduction is bad” or “frugality is only suitable for cheap products”. Rather, the confrontation of the individual barriers with the respective enablers leads to a much deeper discourse within the industry.

Consequently, as shown in Table 2, we derived pairs of barriers and enablers from our empirical data using inductive coding according to Kuckharz (2018) and subsequently compared them along different categories.

Table 2: Barriers and enablers of frugal innovation and engineering

Category	Barrier Perspective	Enabler Perspective
Global competitiveness beyond domestic market	<ul style="list-style-type: none"> • Low-margin products do not solve the growth challenges of incumbents • Low probability of generating a substantial profit with low-cost products in emerging markets • Exploitation of the poor and offering unfavorable offerings tailored to price-sensitive markets 	<ul style="list-style-type: none"> • Tailored solutions for the un(der)served people in emerging nations attract new customer segments neglected by MNCs • High market volume leads to higher global margin despite lower per capita margin
Business strategy and firm survival	<ul style="list-style-type: none"> • Fear of self-cannibalization with low-cost products or products with reduced performance levels and essential functionalities • Image loss and quality concerns pose serious business threats, especially in comparison to evolving high-tech companies of the emerging world 	<ul style="list-style-type: none"> • Frugal products may represent a source of enduring competitive advantage over competitors who exclusively focus on high-end, sophisticated products in the industrialized world • Frugal products represent a strategy against low-end disruption and marginalization
Organizational capabilities	<ul style="list-style-type: none"> • Few available market and engineering know-how about low-cost product development and reduction-oriented optimization • Centralized decision making, performance-maximizing innovation culture, and resource abundance prevent the evolvement of resource-constrained capabilities 	<ul style="list-style-type: none"> • Developing new R&D methods and capabilities for addressing the market needs of the price-sensitive customer segment ("lower-end" and disruptive capabilities) • Developing a deep understanding about the complexity of finding lower-end thresholds and that frugal engineering is more intricate than just reducing performance levels
Frugal outcome and commercialization	<ul style="list-style-type: none"> • Reduction leads to cost optimization but results in lower quality outcomes because the performance has been reduced • Frugal outcomes are less durable and, therefore, less sustainable as they have to be replaced more frequently • Marketing and commercialization concerns as consumers may perceive frugal products as a downgrade compared to the most sophisticated solutions 	<ul style="list-style-type: none"> • Frugality as a sufficiency-oriented engineering approach fosters sustainability and eco-effectiveness • Elimination of unnecessary high-end features and performances that represent a burden for many customers • Possibility to commercialize more adequate products to customer groups that have been neglected for too long • Simplicity and minimalism without (planned) obsolescence as new marketing perspectives
Frugal mindset/culture	<ul style="list-style-type: none"> • Lack of a frugal mindset and frugal paradigms within product development ("<i>performance-improving paradigms</i>") • Inert innovation culture and path dependent settings within the organization and its environment inhibit rapid transformation towards frugal cultures and mindsets • Management orientation is too short-sighted to identify the long-term benefits of frugal product development 	<ul style="list-style-type: none"> • Leadership-induced frugal product development as trigger for larger cultural transformation and evolvement of new, unforeseen business opportunities • Frugal mindset as source for creativity, exploration and experimentation
Corporate sustainability	<ul style="list-style-type: none"> • Fear of poor quality and, therefore, low durability translates into low sustainability performance of products 	<ul style="list-style-type: none"> • Frugal engineering fosters efficiency gains due to lower material demand in products, localization of production and overall improvement of simplicity

- Financial constraints as part of frugal engineering force organizations to favor cheap materials over of high-quality, circular materials
- Rebound effects neutralize the positive sustainability impact of frugal products
- Avoidance of over-engineered and maximized performance levels; return to core functionalities and necessary performance levels of products

4.2 New Perspectives on Frugality

Through juxtaposition of different industry perspectives about frugality, the often-contradictory character of frugality in product development became obvious. On the other hand, it is precisely this juxtaposition that reveals new perspectives and common misconceptions about frugality in product development. Of particular interest in this context is the integration of a paradoxical view that has been the subject of intensive discussion in management research and, more recently, in sustainability management for many years and decades (Poole and van de Ven, 1989; Lüscher and Lewis, 2008; Smith and Lewis, 2011; Hahn et al., 2017; Carmine and De Marchi, 2023).

Following common *contingency-based approaches*, such trade-offs are managed to achieve an alignment with internal and external variables so that eventually conflicts are resolved by the adoption of a situational best-practice strategy (Lawrence and Lorsch, 1967; Smith and Lewis, 2011). In contrast, a *paradoxical* view of organizational tensions seeks a commitment to both contradictory perspectives *simultaneously* (Poole and van de Ven, 1989; Lewis, 2000; Smith and Lewis, 2011). The paradox literature does not emphasize explicit resolution strategies, but focuses on an acceptance of the opposing tensions, which finally supports “firms [to] achieve short-term excellence while ensuring that such performance fuels adaptation and growth enabling long-term success” (Smith and Lewis, 2011, p. 393). A prominent example of paradoxical thinking is provided by Hahn et al. (2014) who argue that the juxtaposition of all elements of corporate sustainability, i.e., economic, environmental, and social aspects, bring forth different management strategies compared to beliefs that try to align ecological and social concerns with the prevailing business logic. In this regard, Hahn et al. (2014) state that a paradoxical view on common sustainability tensions in organizations may result in more prudent and differentiated behaviors, and at the same time foster green innovations outside established paradigms and routines.

We highlight that the argumentation is also valid within the frugality debate. If frugality is embedded in the existing business logic, the contradictory interrelatedness of the enablers and barriers *persists*. Even if a situational best-fit solution is found in a specific product development context using contingency approaches (think, e.g., of the determination of the performance level of a specific product), the opposing views are not dissolved. By means of paradoxical framing, however, companies can succeed in accepting the opposing forces, develop more suitable, adequately engineered innovations and apply novel innovation paradigms.

From an organizational point of view, the outcome of these paradoxes is what scholars describe as “constraint-based thinking” (Agarwal et al., 2021). The ability to “do more with less for more” results in “affordable green excellence” (Herstatt and Tiwari, 2020) and products that encompass a golden mean with neither over-engineered nor under-engineered performance levels (Tiwari and Herstatt, 2020; Achtelik et al., 2023). Practically speaking, it is not supportive to understand frugality and frugal innovations as a *binary construct* (i.e., frugal or not frugal). In contrast, we argue that the deliberate adoption of frugal engineering as a novel approach to product development might lead to a broader acceptance in the business world.

To the best of the authors' knowledge, these views have not sufficiently found their way into the frugality discourse so far and, therefore, demand more scientific attention. Building on our empirical work at our Institute at the Hamburg University of Technology (TUHH), we juxtapose these conflicting views derived from the industrial landscape and provide a new perspective that might represent a first approach to resolve the emerging tensions within new product development. The final results are shown in Table 3.

Table 3: New perspectives on frugal innovation and engineering

Category	Balanced Perspective
Global competitiveness beyond domestic market	Frugal engineering as a "win-win-approach": realizing incumbent growth and expansion into new markets while simultaneously foster social and ecological development in both advanced and emerging economies.
Business strategy and firm survival	Frugal engineering minimizes the change of low-end disruption through the offering of cost-effective, "good-enough", and high-quality products tailored to customer needs – therefore representing a promising global innovation strategy.
Organizational capabilities	Frugal engineering requires business activities outside established paradigms and capabilities thus forcing the organization to challenge shared assumptions, available know-how, and operative routines through organizational learning.
Frugal outcome and commercialization	Frugal engineering leads to more customer-oriented, adequately engineered innovations through avoidance of over-engineering and under-engineering.
Frugal mindset/culture	Frugal engineering represents a chance to adapt inert innovation mindsets and cultures through ambidextrous organizational designs and the willingness to both exploit and explore simultaneously.
Corporate sustainability	Frugal engineering resolves the tensions between economic and ecological aspects within the sustainability discourse by reducing both development cost and total cost of ownership (TCO) for more sustainable products.

The balanced perspective alongside the previously identified categories once more underscores prevalent misconceptions of frugality in the industry. First and foremost, this includes the perception that *reduction* is a "bad thing" and inevitably results in inferior products of questionable quality. However, as we can see from the balanced perspective, the outcomes of a frugal development process are by no means worse (otherwise they would not be frugal in the definitional sense), but more *suitable*. In particular, our action research has emphasized the advanced implications for organizational learning when frugal approaches are integrated, corresponding paradigms are realigned and new competencies in favor of simplicity emerge. Product development characterized by over-engineering and an ongoing exploitation of the technical potential can achieve greater customer centricity through frugal approaches. Frugal engineering forces the organization to radically question its previous technical assumptions, methods, specifications and processes and, if necessary, to explore new development approaches. Specifically for the Western automotive industry, frugality is therefore an indispensable means of avoiding lower-end disruption in the face of increasing global competition and of maintaining its competitive edge.

Finally, frugal engineering can be characterized as one enabler for sustainable innovation, since its focus on simplicity and thriftiness is inherently sustainable. Thus, we propose that frugality is a truly win-win-approach in this regard. On the one side, it promotes sustainable practices within product development, on the other side, it strengthens the affordability of sustainable products and its associated development processes. In many cases, sustainable products, such as secondary materials,

are characterized by higher costs than their “non-sustainable”, virgin counterparts. Frugal engineering addresses this dilemma, by significantly reducing material costs, development efforts and TCO. With that, we also want to disprove the misconception that frugality results in cheap products that forgo sustainable attributes owing to the high cost optimization as part of the development. If frugality is understood as an overarching paradigm that leads to holistically better products (“affordable green excellence”), then any of the aforementioned concerns are obviously unjustified because they are incompatible with the core idea of frugality.

5 Conclusion

In our empirical research, we were often confronted with a two-sided perception of frugality. Managers and industry experts responded with conviction, openness and curiosity about introducing frugal thinking into their organizations. Similarly, people were skeptical and more hesitant about subtractive thinking. As Adams et al. (2021) point out in their paper on the human tendency to approach problems with an additive attitude, this is not surprising. Frugality seems incompatible with the dominant performance-enhancing paradigms of our business world. While people have largely recognized the promise of frugal engineering, their response has too often been a “yes, I see your point, but...”. We believe that many of these concerns are based on misconceptions about the construct itself. We hope that our research, presented in this working paper, has provided further food for thought for both academics and practitioners. However, in order for frugal engineering to gain wider acceptance, it is necessary for research – in close collaboration with industry – to produce successful case studies that demonstrate the superiority of frugal approaches in many areas of product development.

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