

# Frugal Processes: An Empirical Investigation Into the Operations of Resource-Constrained Firms

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**Abstract**—The severe resource constraints that characterize markets at the bottom of the world’s economic pyramid have forced firms to innovate both their products and processes. However, discourse in frugal innovation literature on how firms can design frugal processes in response to the resource constraints they face remains relatively sparse. Based on a systematic literature review, in this article we consolidate existing work on the process echelon of frugal innovation. We outline three ways frugal processes that have been conceptualized in the literature thus far, and distill their key characteristics. Based on an exploration of the supply chains of 87 small- and medium-sized enterprises, we show how firms configure these characteristics to overcome resource constraints at each stage of their supply chain. Ultimately, we propose three archetypes of a frugal supply chain that firms can strategically adopt. Firms with the primary goal of increasing consumer access to affordable products opt for a supply-chain structure that favors traditional economies of scale, and postpone any decentralization as further downstream as possible. In contrast, firms aiming to provide consumers with greener alternatives can adopt a hyper-decentralized structure throughout their supply-chain, which is made economically viable through low-cost approaches to distributed manufacturing. Firms interested in empowering local communities should consider hybrid structures that balance the high costs of investments in local capabilities.

**Index Terms**—Base of the pyramid, bottom of the pyramid, emerging markets, frugal innovation, process innovation, small- and medium-sized enterprises, supply-chain management, sustainability, sustainable operations.

## I. INTRODUCTION

**F**RUGAL innovation emerged from highly practice-oriented origins, as an approach by companies trying to achieve the price and functionality requirements of their customers at the bottom of the world economic pyramid, who, at times, earn as little as two United States Dollar (USD) a day [58]. Companies operating in bottom of the pyramid markets frequently face constraints such as limited material resources, limited financial resources, as well as limited institutional or infrastructural

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systems [8], [17]. The ability to overcome these constraints is key to frugal innovation [95]. Successfully implementing frugal innovation entails both an understanding of the frugal products themselves, but also how they can be designed, produced, and successfully delivered under severe resource constraints [24].

Discourse on frugal innovation has thus far focused on frugal products. Previous research explored what makes frugal products attractive in their respective market, primarily in the context of markets at the bottom of the pyramid [56], and what differentiates these products from their nonfrugal counterparts regardless of market context [91]. Depending on the requirements and financial abilities of the target customer group, frugal products are cheaper, yet still provide an adequate answer to the customers’ unique needs [91].

In contrast to the proliferation of work on frugal products, an understanding of how companies can design their processes to successfully address resource constraints remains underdeveloped, and frugal processes remain undertheorized. Studying how resource constraints influence processes in the different stages of a company’s supply chain is crucial from a managerial perspective. Bhatti and Ventresca [17 p. 15] surmised that “[...] any study of frugal innovation should consider how resource constraints are faced both upstream and downstream for all users at any point of the value chain [...] affordability is not just a concern at the end point or outcome of innovation.” We aim to address this research gap by focusing on the process echelon of frugal innovation. We analyze how frugal processes can be designed by firms in order to overcome resource constraints, by exploring the supply chains of companies operating in bottom of the pyramid markets. We aim to provide readers with the answer to the following questions.

- 1) How have frugal processes been conceptualized and addressed as part of broader frugal innovation research?
- 2) What are the key characteristics of frugal processes and how can they best be configured to tackle resource constraints across supply chains at the bottom of the pyramid?

In this article, we identify nine different process characteristics synthesized from frugal innovation literature, and show how they can be adopted at the bottom of the pyramid by firms with different primary goals. We show how firms with different goals face resource constraints and achieve frugality at each stage of their supply chain, as well as strategically, at a supply-chain level. We work at the intersection of frugal innovation, bottom of the pyramid, and supply-chain research. However, our findings can also provide a robust and empirically oriented starting point for future work at the intersection of

frugal innovation and supply chains in different market contexts. For example, identifying best practices for the design of frugal processes in resource-constrained contexts outside the bottom of the pyramid or in bottom of the pyramid markets in different geographic settings.

The rest of this article is organized as follows. In Section II, we outline the research design adopted for exploring the existing literature and empirical data. In Section III, we showcase the key findings from the systematic literature review; first, we outline three viewpoints on how frugal processes can be conceptualized, and second, we introduce the identified characteristics associated with frugal processes in the literature. In Section IV, we outline the empirical findings from our exploration of the supply chains of firms operating at the bottom of the pyramid. In Section V, we discuss our findings and provide avenues for further research at the intersection of supply-chain management, frugal innovation, and bottom of the pyramid markets. Finally, Section VI concludes this article.

## II. METHODOLOGY

### A. Overview of Research Design

To explore the abovementioned questions, we adopt a twofold research approach, grounded in both theory and empirics. In the first research step, we conduct a systematic review of the existing state-of-the-art of frugal innovation literature, in order to consolidate the existing knowledge on frugal processes. We explore how frugal processes have been conceptualized and addressed in frugal innovation research and identify their key characteristics. In the second research step, we empirically explore the manifestation of the identified characteristics across the supply chains of small- and medium-sized enterprises operating at the bottom of the pyramid.

The decision to first carry out a systematic literature review was driven by the motivation that existing reviews on frugal innovation take a product perspective (see Table I). This results in certain limitations when trying to transfer the acquired knowledge to frugal processes. For example, in their systematic review, Agarwal *et al.*, [1], [2] clustered the key characteristics of frugal innovation, with a perspective of frugal products in mind. However, the cluster analysis also resulted in a large number of miscellaneous attributes that could not be assigned to a single category, such as “fast,” “lean,” and “inclusive.” These were grouped together under the name “prescriptive variables.” The authors note that “The ambiguity in the prescriptive variables exhibits limited research focus on the innovation process and different means or approaches toward achieving the required product characteristics” [2, p. 11]. By explicitly focusing our review on the process echelon of frugal innovation and identifying the characteristics of frugal processes, we aim to build on existing work and provide a uniform understanding and theoretical foundation for future research exploring this echelon.

The decision to carry out an empirical investigation was driven by two main concerns echoed by previous frugal innovation researchers. First, scholars in the field note the lack of empirical work in general, and the prevalence of theory building that is

TABLE I  
SELECTED SYSTEMATIC REVIEWS ON FRUGAL INNOVATION

	Papers Reviewed	Purpose	Process Perspective
Weyrauch and Herstatt, 2016 [91]	62	Consolidate existing knowledge on frugal innovation attributes, and identify key product characteristics	No
Agarwal <i>et al.</i> , 2017 [2]	117	Systematically compare different innovations and identify clusters of frugal product characteristics	No
Hossain, 2018 [34]	101	Identifies input, success and impeding factors, and outputs of frugal innovation	Implicit
Pisoni <i>et al.</i> , 2018 [56]	113	Explore the development of the frugal innovation literature and derive directions for future research	Implicit
Rosca <i>et al.</i> , 2018 [67]	64	Explore the relationship between frugal innovation and sustainable development	Implicit
<i>Current Review</i>	81	<i>Consolidate existing knowledge on frugal processes and identify their key characteristics</i>	<i>Explicit</i>

grounded in anecdotal examples in particular [73], [89]. Second, the existing empirical work in the field is often based on a relatively narrow pool of cases [33]. Agarwal *et al.* [2, p. 11] noted that “There is a potential scope of skewness in the review results due to repeated illustrations and case examples re-used and re-published in different outlets. An example of this is the case of ‘Tata Nano.’ [...] In the SLR conducted, 70% of the articles on Indian automotive industry use Tata Nano as the case example.” In particular, empirical work on smaller firms operating under resource constraints is an underexplored but promising direction for future research [56].

### B. Systematic Literature Review

1) *Article Selection and Data Collection:* In order to identify possible articles for the review, the term “frugal innovation” was queried in both SCOPUS and Web of Science, limited only by the language of the publication (English). The term “frugal innovation” was chosen as it is fast becoming an umbrella term for innovating under constraints, despite similar terms used in earlier years [79]. These databases were chosen due to their comprehensive coverage of the different range of disciplines that are relevant to the frugal innovation phenomena, with SCOPUS in particular as one of the most comprehensive databases for management and the social sciences [56]. The query resulted in 314 hits in total. The initial bibliometric details of the articles were inputted into an organized excel protocol in order to ensure a systematic review process thereafter.

After duplicate hits were removed, we began the process of selecting suitable articles. First, the publications’ titles and

abstracts were screened for their applicability. In keeping with the selection approach of previous reviews [56], [67], we excluded articles from the broader social-sciences and management fields that refer to frugal innovation only in a passing or with very limited focus (for example, [3]). We also excluded articles in highly specialized technical fields (such as medicine or psychology) that refer to the term either in a colloquial sense, or do not aim to provide an explicit connection to any broader stream in management, innovation, or organization literature (for example, [10]). This screening resulted in 160 articles.

The remaining articles were then limited to include only journal publications, excluding all book chapters and conference proceedings, resulting in a total of 106 publications. This exclusion was carried out at this stage of the control process, due to the large number of items in conference proceedings that were identified to have been expanded into journal publications. The difficulty in clearly distinguishing between those that have been expanded and those that have not led us to the decision to limit the scope of the review to include only final published reviews and articles in journals, in order to avoid possible overrepresentation of elements in our findings. After reading the full texts, 25 articles did not contribute enough content to the topic to warrant inclusion. Thus, a final total of 81 articles were coded for the review.

2) *Article Coding*: For each article, we identified whether the crux of the text focuses on frugal products ( $n = 47$ ) or frugal processes ( $n = 34$ ). For articles that focus on processes, we noted the supply-chain stage the paper addressed, and iteratively formed five standard categories. The first category is the supply-chain stage of procurement ( $n = 16$ ), which refers to activities such as product development, supplier selection, or material sourcing. The second stage is production ( $n = 3$ ), which refers to the transformation of inputs and raw materials into end products. The third stage is distribution ( $n = 2$ ), which refers to marketing activities, sales, or last-mile delivery. Two additional categories were added during the iterative coding, in order to accommodate the diversity of outlooks in the literature. The first new category was dubbed “holistic” ( $n = 6$ ) and includes papers that take an overarching approach to the processes studied by adopting a business model or (entire) supply-chain perspective. The second additional category was dubbed “inclusivity focused” ( $n = 7$ ) articles, and includes papers that focus on the social sustainability outcomes of a conglomerate of different processes.

For the 34 process-focused articles, the characteristics of the processes studied were identified from the texts through an iterative bottom-up approach. For example, the sentences “[frugal] innovations are not just about providing low-cost care for underserved populations. Rather, they drive value by [...] focusing on continuous improvement” [15 p. 1916], as well as “employees are highly encouraged to experiment novel methods and approaches concerning the production processes.” [20, p. 242], alongside additional text fragments, relate to the characteristic “iterative.” This inductive procedure resulted in a total of nine characteristics of frugal processes, which were then grouped into four overarching categories (see Table II for an overview).

TABLE II  
CATEGORIZATION OF FRUGAL PROCESS CHARACTERISTICS

Description	Process Characteristics
Characteristics related to dependency on resources	Waste Minimization Self-sustaining
Characteristics related to process complexity	Technology-enabled Simplified
Characteristics related to external collaboration	Localized Carried out in collaboration with other stakeholders Integrate the local population
Characteristics related to time-dynamics of processes	Iterative Flexible

### C. *Exploratory Multiple Case-Study Design*

1) *Case Selection and Data Collection*: In this second stage of research, we aimed to build on the existing literature on frugal processes and their identified characteristics. We conducted a cross-case analysis of 87 small- and medium-sized enterprises operating in bottom of the pyramid markets.

First, in order to identify potential cases, we utilized the award database “SEED.” The SEED award was jointly founded by the United Nations Environment Program, the International Union for the Conservation of Nature, and the United Nations Development Program, in order to identify outstanding initiatives operating at the bottom of the pyramid. We utilized the award database to gather the initial pool of possible cases, in order to ensure that all cases would have already been vetted by an experienced jury on their innovativeness, but particularly their scalability and economic potential, as such figures are challenging to find publicly. This selection procedure is ideal for providing insights on best practices, in keeping with the aims of our research.

However, choosing cases from a pool of preselected firms also corresponds to possible limitations to the generalizability of our findings. First, one of the criteria for the award is that ventures also engage in partnership with other stakeholder groups. Therefore, the absolute prevalence of characteristics related to external collaboration, for example, carried out in collaboration with other stakeholders cannot be generalized to all ventures in bottom of the pyramid markets. However, the relative prevalence of this approach in the different supply-chain stages is less impacted. Second, the final sample of cases is strongly concentrated in Africa, with 83% of cases ( $n = 72$ ) operating in different countries in the African continent, 13% from Asia Pacific ( $n = 11$ ), and 5% from Latin America ( $n = 4$ ). However, particularly when considering the strong critique on the narrow geographic focus in frugal innovation literature in Asia, and, more specifically, India [2], increasing the empirical work in the context of the African continent is beneficial [36].

The process of selecting the cases comprised of several steps. First, we compiled a list of all ventures displayed in the SEED website between the years 2003 and 2018. We incorporated all industries included in the SEED database, resulting in ventures

operating in the energy, green technology, food and agriculture, and waste and sanitation sectors. This resulted in a list of 213 ventures in total. We collected basic information on each case from the publicly available data on the database, such as year of award, name of venture, and country of operation. These initial bibliometric details were inputted into an organized case-study protocol in excel, to ensure a systematic process for further case selection, as well as the subsequent within-case and cross-case analyses.

As a second step, we complemented the data provided by the award database by collecting additional secondary data. We collected information on the procurement, production, and distribution activities of each venture, whereby the understanding of each stage of the supply chain is equivalent to that used previously in the literature review. Moreover, we collected data on each firm's self-reported mission statement and impact, in order to identify the primary goals that drive each firm. The secondary data collection was carried out by two coders, and typically involved multiple sources per venture, comprised of both text and video data. Types of sources used include company websites, official social-media outlets, and sources from external third parties, such as reputable news outlets or consulting reports, in order to ensure triangulation of information. Firms that lacked public information on their supply-chain practices were excluded, resulting in 135 potential cases. Finally, we excluded firms that operated from the bottom of the pyramid, but did not also sell to bottom of the pyramid consumers. This resulted in a final total of 87 case studies.

2) *Within- and Cross-Case Analysis*: The exploration of data consisted of a within-case analysis of the supply chain of each of the 87 ventures, as well as a cross-case analysis. The previously identified frugal process characteristics were utilized as the initial top-down dimensions for our empirical investigation in the within-case analysis. For each venture, the information on each supply-chain stage was first analyzed for prevalence of each process characteristics. Coders inputted a binary yes or no, for whether each of its supply-chain stages demonstrated any of the frugal process characteristics. Then, a bottom-up approach was utilized to thematically analyze the text data along two dimensions.

The first dimension relates to the primary goals of firms in our study, based on their mission statement and supplementary information on their self-declared impact. The three main goals identified were as follows:

- 1) ventures aiming to increase consumer access to affordable products;
- 2) ventures aiming to encourage local empowerment;
- 3) ventures aiming to provide consumers with greener alternatives.

For example, the company FrontierMarkets, which stated that “[...] There was a Last Mile access gap—and Frontier Markets was launched to close it” [54], or the company WanaEnergy, which noted that the firm “exist[s] to transform the livelihood of our people, socially and economically, by providing them with affordable clean cooking solutions” were both classified as firms with a primary goal of increasing access of consumers to more affordable products.

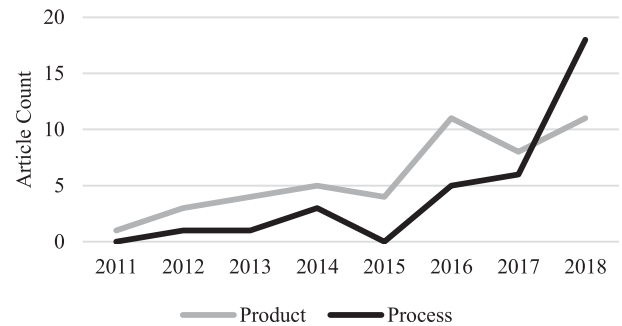


Fig. 1. Number of new publications focusing on frugal products versus processes.

The second dimension relates to assessing how the identified characteristics manifest at each stage of the supply chain. For example, in manufacturing, creating “self-sustaining” processes can be done by converting mobile units, such as shipping containers, into small production workshops. These workshops can be deployed and function anywhere in rural areas, including locations without connection to the main electricity grid, or without skilled employees. We have dubbed this a “production-in-a-box” approach. Then, we assessed whether these approaches differ for firms pursuing the three different primary goals. For example, a “production-in-a-box” approach is mainly utilized by firms with aiming to provide greener alternatives, and less so by firms with other primary goals. Finally, we explored how the characteristics of processes at one stage of the supply relate to those in the other stages. We aimed to gauge whether overarching supply-chain archetypes for achieving frugality exist. Thus, our analysis takes place both within the supply chain, and at the supply-chain level, in keeping with best-practice recommendations of scholars in the field [53].

### III. FRUGAL PROCESSES IN THE LITERATURE

Academic interest in the phenomena of frugal innovation is increasing exponentially. The majority of existing literature on frugal innovation takes a product focus ( $n = 47$ ), but the more recent articles study its processes. With academic interest surging particularly in 2018 (see Fig. 1), articles on frugal processes are growing into a substantial body of the literature ( $n = 34$ ). In Section III-A, we aim to answer our first research question by delineating three key ways that frugal processes have been conceptualized in frugal innovation literature thus far (see Table III).

#### A. Conceptualizations of Frugal Processes

One earlier conceptualization views “frugal innovation” as equivalent to frugal products (see Fig. 3). Therefore, articles subscribing to this understanding study how severe resource constraints impact the process of product development in particular (see Fig. 2). In fact, the word “innovating” is at times even used interchangeably with “developing” products. For example, Agarwal and Brem [1, p. 37] wrote that companies at the bottom of the pyramid “[...] realized the special competencies of local population in innovating cost-effective products [...]”

TABLE III  
CONCEPTUALIZATIONS OF FRUGAL PROCESSES

	I: Focus on frugal products	II: Disambiguation into a frugal mindset, process and product	III: Focus on non-product innovation
<b>What is frugal innovation?</b>	Frugal innovation is understood as frugal products or, alternatively, as frugal products and their development.	Frugal innovation is understood as a multi-echelon phenomenon: a frugal mindset, frugal process and frugal product.	Frugal innovation is understood as a non-technological innovation as well (for example, frugal business models).
<b>What is the role of frugal processes?</b>	Strong focus on frugal product development.	Incorporation of processes beyond product development.	Frugal processes as the innovation outcome itself.
<b>Notable example</b>	Frugal Engineering	Lean Manufacturing	Dabbawalas of Mumbai
<b>Gap it aims to address</b>	Takes into account how frugal products are developed, rather than only focusing on what they are (products themselves and their characteristics) [44]	Takes into account that resource constraints impact all processes in the supply chain, not only product development [17]	Takes into account that frugal innovation can also be of a non-technological nature.
<b>Origin in Literature</b>	Frugal engineering was coined by Carlos Ghosn, CEO of Renault-Nissan, in reference to the development of the “TATA Nano” [71], but is becoming an umbrella term for the process of developing frugal products.	The disambiguation was first proposed by Soni and Kirshnan [77] and has been widely adopted since.	The non-technological nature of frugal innovation was already proposed in the seminal paper on frugal innovation by the Economist [24] but explored in more depth only relatively later.

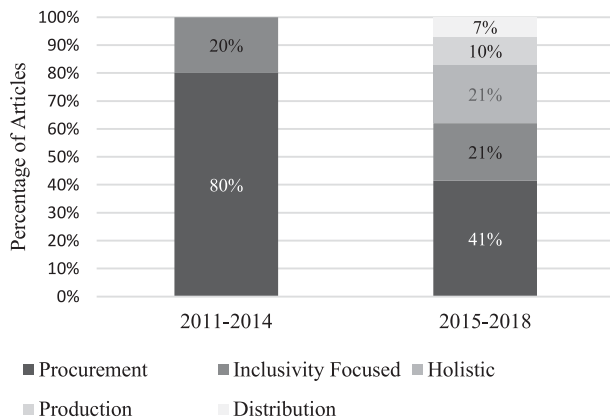


Fig. 2. Diversification in the supply-chain stage studied.

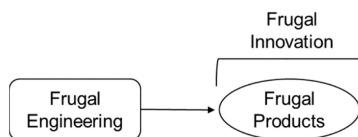


Fig. 3. Conceptualization I: Frugal innovation as frugal products and their development.

Some articles use “frugal innovation” as an encompassing term for both the frugal products themselves, as well as their product development process [40], [73]. For example, Ojha [40, p. 7] noted that “[...] the term frugal innovation refers to the systematic innovation processes that had been adopted in order to develop high-end low-cost technology products for markets such as India [...]” The process of developing frugal products can be carried out through many different approaches, such as entrepreneurial bricolage or modularity [30], [47], [59],

[73]. However, one of the more prominent examples of product development under constraints is “frugal engineering.” Sehgal *et al.* [71] explained that “Rather than simply cutting costs, frugal engineering adopts a clean-sheet approach to product development that seeks to maximize value for the customers while minimizing unwanted costs and excessive resource consumption in the first place” [71]. Therefore, the term “frugal engineering” is often used to refer to the process of developing frugal products [61], [71], [73], whereas the term “frugal innovation” is used to refer to the products themselves.

Proponents of this conceptualization consider the product development process to be critical, arguing that the majority of costs and, therefore, the subsequent affordability of the end products are decided upon during this phase. For example, Winterhalter *et al.* [89, p. 6] noted that “The frugal product architecture is not only crucial to enable the application innovation but the design of the products itself is the biggest lever for cost reduction.” Another example is given by Rao [61, p. 51] who noted that “[...] the design and manufacturing of a frugal product from scratch is assumed to be the primary approach for achieving frugality with the utilization of other features, such as supply-chain and quality-control tests, being secondary or ancillary.”

Despite the importance of frugal product development, “Frugal innovation is not just about redesigning products; it involves rethinking entire production processes and business models” [24]. In this vein, an alternative conceptualization was outlined by Soni and Krishnan [77]. They proposed to view frugal innovation as a multiechelon phenomenon rather than a monolithic entity of frugal products sweeping developing nations (see Fig. 4). Their typology of frugal innovation comprised of frugal products, but also a frugal mindset and frugal processes, and was widely adopted in various formats [1]. Soni and Krishnan [77] provided the following illustrative example for each echelon:

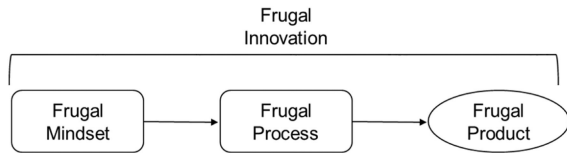


Fig. 4. Conceptualization II: Frugal innovation as a multiechelon phenomenon.

“[...] a rural housewife who prudently manages her budget to buy groceries for her family is exhibiting a frugal mindset; a carpenter who has very limited tools may exercise a frugal process in making beautiful furniture; and an innovator of a scooter-mounted flourmill has actually created a frugal offering” (p. 10).

Similar to prior conceptualizations, frugal processes here are still primarily understood and defined in relation to their desired outcome, frugal products. For example, Belkadi *et al.* [12] built on the work of Tiwari and Herstatt [79] and stated that “The outcomes of a frugal process are new products and services that ‘seek to minimize the use of resources in the complete value chain with the objective of reducing the cost of ownership [...]’” (p. 1). Another example is given by Rosca *et al.* [66], who built on the work of Anderson and Markides [6] and noted that “[...] the authors point out that developing frugal products implies the creation of a new ‘who’, ‘what’ and ‘how’.” (p. 5). However, this conceptualization differs from the former in that it also considers how severe resource constraints impact processes in the later stages of the supply chain, such as material sourcing, manufacturing, or distribution (see Fig. 2).

A notable example for manufacturing under resource constraints is “Lean Manufacturing,” which originated in Japan after the Second World War. In response to the severe resource constraints the Japanese automotive industry faced, Taiichi Ohno, the CEO of Toyota, redesigned the company’s entire manufacturing system [90]. The new manufacturing processes focused on maximal creation of value for the end customer and elimination of nonvalue adding activities, referred to as “waste” [90]. The general philosophy as well as specific principles and tools of the lean production system were fundamentally different to the dominant approaches used in developed economies at the time [72].

Proponents of this conceptualization highlight the importance of addressing all processes in the supply chain, arguing that resource constraints are felt across the entire supply chain and therefore should not be studied only in the context of product development [17]. In other words, though frugal processes do not necessarily need to result in frugal products, frugal products require all processes associated with them to be frugal as well [77]. For example, it has been well established that the price demands of original-equipment manufacturers in India impacted the subsequent demands for cost-effectiveness across the entire supply chain [40], [81]. Ojha [40] articulates that “When the Indian OEMs [original equipment manufacturers] became cost conscious in the late 1990s, we also assessed that off-the-shelf products from Germany were not relevant for India. There was a price war among the OEMs. The effect gradually went up the

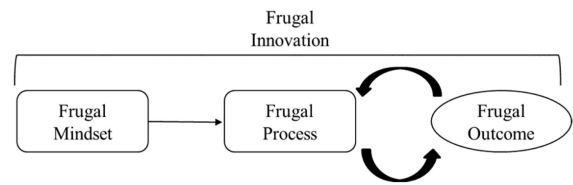


Fig. 5. Conceptualization III: Frugal innovation as a nontechnological innovation.

supply chain and we realized we had a gap [...]” Additionally, studying the impact of resource constraints on distribution processes was noted as crucial because they directly influence companies’ success in scaling up and profitably capitalizing on their innovation. One challenge in this vein is that many ventures fall into a “local trap” and remain at a grassroots level only. As noted by Soni and Krishnan [77, p. 35] that “[...] while such [frugal] solutions are adept at addressing the local problem reasonably well, they often fail to scale up [...].”

The third conceptualization of frugal innovation takes into account that frugal innovation can refer to nonproduct innovation as well. The understanding of frugal innovation as a nontechnological innovation, such as frugal business models, was already proposed in the seminal paper by The Economist [24], but only explored in more depth relatively later (see Fig. 2). Recent articles study new business models (for example, [36], [43], [66], and [89]) or supply chains [74]. Articles subscribing to this viewpoint study how severe resource constraints impact all the processes related to the design and dissemination of frugal products, but also focus on the processes as the innovation in itself (see Fig. 5). For example, building on the understanding of Radjou and Prabhu [94], Hossain *et al.* [35 p. 133] defined frugal innovation as a “resource scarce solution (i.e., product, service, process, or business model) that is designed and implemented despite financial, technological, material, or other resource constraints [...].” A notable example for frugal innovation of a nontechnological nature is the supply chain of the Dabbawalas’ lunch-box deliveries in Mumbai, India [74]. The Dabbawalas pick up personalized lunchboxes from the homes of their customers, deliver them to their respective office across the city, and then return the empty lunch box back to their individual homes. Through an ingeniously designed color-based code system, and using only public transportation and bicycles, the Dabbawalas manage a highly complex network and deliver over 200 000 lunchboxes daily, while maintaining an astounding accuracy rate (service level) of 99.99% (see [74]).

## B. Characteristics of Frugal Processes

In Section III-A, we outlined how frugal processes can be conceptualized, and the growing awareness for the need to achieve frugality at all stages of the supply chain. In the following section, we introduce nine characteristics that were identified in the literature as contributing to frugality of processes (see Table IV).

1) *Characteristics Related to Dependence on Resources:* Many papers describe frugal processes in relation to the

resources they require; both in terms of how efficiently they utilize their available resources to avoid waste, as well as whether they avoid the use of certain resources altogether, to become self-sustaining. The concept of “waste” is largely understood in literature as unused inputs or material, as well as by-products or environmental waste created in processes [73]. Methods for minimizing waste are most often discussed in the context of procurement or production processes and are significantly less prominent in discussions on distribution. Self-sustaining processes attempt to overcome resource scarcity by designing processes to be carried out with as little inputs as possible in the first place. For example, healthcare services should be able to be carried out without seemingly compulsory resources, such access to electricity, professional staff, or supplementary medical equipment, all of which could be lacking in severely resource-constrained environments [89].

2) *Characteristics Related to Process Complexity*: Many papers address the need to reduce the complexity of the processes carried out under resource constraints. This involves both the simplification of some processes, as well as the introduction of different technologies within others. A reduction in complexity is noted as necessary in product development [18], [44], [82] and production [20], [73] in particular. The integration of technology within processes is a relatively new topic in literature, despite many existing debates on the necessary level of technology sophistication for products. For example, Rao [60], who introduced the concept of “advanced frugal innovations,” or Ojha [40] who discussed whether frugal products are simply modified technology from developed economies that are pushed onto the bottom of the pyramid. Similar discussions on the role of technology within processes are rare. Despite a multitude of papers in our review that noted the important role technology or digital components play in frugal processes, these statements are usually hidden deep within articles and are rarely the focal point of the paper itself. One exception is given in [36], which addressed the role of integrating technology within frugal business models. The authors echo the gap of research on technology-enabled frugal processes, noting that “While there are examples of IT related frugal innovations, like GE’s affordable ultrasound device or Google’s low cost smart phone, the discussion does not extend to the enabling role of IT in the business model [...]” [36, p. 2].

3) *Characteristics Related to Collaboration*: Frugal processes are often characterized as highly collaborative in nature. Literature often encourages firms to localize their processes, carry out certain processes in collaboration with nontraditional stakeholders, such as nongovernmental organizations, as well as to integrate the local population in the various supply-chain stages. Localization is often discussed particularly in relation to product development. Some authors argue that research and development should be carried out in close proximity to the target market [73], whereas others argue that such processes can also be successfully conducted in an entirely different country [37]. Localization is also discussed in relation to lower costs, whereby a core factor for cost reduction through localization is cheaper labor in different countries. Although authors in the

field note that “cheap labour does not suffice for this type of innovation” [83, p. 62], a subtle prevalence of lower wages as an enabler of cost reduction in frugal processes was prevalent nonetheless. For example, Hossain [34, p. 931] noted that the “[...] Chinese harbor crane manufacturer ZPMC can hire 40 times more engineers in China than its counterparts in Germany for the same cost [...] enabling ZPMC to offer products at a very low price.” Another example is given by Winterhalter *et al.* [89, p. 7], who noted that “The cost of manual technical labor in India is about 10% of the costs in the developed world. Hence we are able to provide low cost for low volumes.”

Collaboration with multiple stakeholders is often discussed in relation to product development, and has also been dubbed “polycentric development” [83]. In particular, integrating local population at the bottom of the pyramid is considered highly advisable due to the “social embeddedness” and unique insights only they can provide companies with [73]. For example, Van Beers *et al.* [83] explored how Unilever developed and marketed its single-use detergent sachets. One of the key initial hindrances to successfully marketing the product, was a weak understanding of the needs of potential consumers at bottom of the pyramid. More specifically, the company had wrongly assumed that the local employees, who are from the same country but not the same socio-economic background, would be knowledgeable of the accurate needs of people in deep poverty. The authors noted that “[...] local African Unilever employees seemed to be less open and connected to the customers in the BoP [bottom of the pyramid] than had been expected by the company’s marketing department” [83, p. 65].

4) *Characteristics Related to Time Dynamics of Processes*: Frugal processes are often characterized as highly dynamic and quick-paced. Processes tend to be iterative and focused on incremental improvements. Additionally, they are designed to be easily adaptable, in order to ensure a great deal of flexibility. Iterative processes for continuous improvement were noted as important particularly in procurement. For example, during product development, companies often go through iterative experimentation [36]. For example, Rao [61 p. 50] noted that “multiple design iterations might be warranted even after adopting a rigorous design process to iron out all the weak spots of a frugal product.” In addition, employee experimentation or trial-and-error is considered vital in production for overall continuous improvement (see [15] and [20]).

In this section, we introduced nine key characteristics of frugal processes. We find that “There is consensus in the literature that frugal innovation’s core focus is low cost [...] However, there are different opinions regarding the way that is achieved” [66]. When it comes to the processes of frugal innovation, companies are encouraged to reduce costs by introducing elements of centralized mass production on the one hand [77], [89], but on the other hand, a highly localized and “polycentric” approach is also encouraged [67], [83]. In some cases, companies are encouraged to substantially simplify processes [73] and strip them of technology. In other cases, authors highlight the opportunity to reduce costs by introducing new technologies within processes [36]. In the following section, we explore how the

TABLE IV  
OVERVIEW OF PROCESS CHARACTERISTICS IN FRUGAL INNOVATION LITERATURE

Frugal processes are	Prevalence in process-focused articles	Illustrative quotes
Minimal waste created and high in utilization of resources on hand	53% (18/34)	“We [Hyundai India] eliminate all sorts of costly aspects from our product development processes so that not only we can pass the savings on to our customers, but also can design and develop vehicles from less materials, with more performance and in less time” [73, p. 15]; “[...] one necessary condition for frugal innovations to be sustainable is the frugal use of natural resources in the production processes” / “Recycling is performed instead of sourcing. Many companies use recycling materials as raw materials for reducing procurement costs and increasing acceptance at the same time.” [67, p 15] and [66, p. 20]; “Frugality means the ability to get more from less by making ingenious use of existing resources at hand, and to take cost out of the entire innovation process (i.e. from the generation of ideas commercialization of products and services”. [43, p. 363]; “As outlined by our cases, the firms had an extreme focus on cost minimization in all value creation elements including R&D, supply chain, manufacturing, and sales.” [89, p. 7]
Localized	53% (18/34)	“Frequently frugal innovation determine[s] localization of value chain with strong focus on local manufacturing, local suppliers and raw materials acquisition and local distribution channels” [67, p. 15] “Since frugal innovation calls for addressing the local market by adopting local means of innovation, local embeddedness tips over embeddedness in the global (or parent) value chain if an MNC aspires to innovate frugally.” [77, p. 41]
Technology-enabled	44% (15/34)	“[the frugal innovation’s] simplicity and cost reduction did not occur through stripping away or lower resource use, but rather through a reconfiguration and redesign utilizing high tech components [...] Raw material, financial and production resources are more limited at the BoP (production constraints) creating challenges for value creation. Additionally, market access, power, and security (transactional constraints) are also limited or nonexistent, making value capture more difficult [...] The dual challenge of value creation and value capture could be overcome by technology” [36, p.10] “[the studied company] adopts an ‘internet plus’ management mode to get through different links (e.g. supply, production, R&D, sales) to digitize its entire value chain and ultimately to realize high synergy with low waste.” [43, p.365]
Integrate local population	32% (11/34)	“[...] dedicated marketing and sales units/channels for rural customers – often located in the emerging market and led by local people – support these units. [including locals in sales] enabled the firms to appropriate further cost savings compared to building new channels or train existing sales people for selling frugal products.” (see [89, p. 7]) “[...] [The frugal product] is distributed by villagers who are trained as salespersons on a commission of 3 USD per unit sold.” [35, p. 12] “The inclusive element of frugal innovation concentrates on integrating excluded populations into the formal economy and thus regards the poor not only as potential consumers but also as producers and suppliers.” (see[50, p. 222]) “One change involved Unilever’s distribution network, which was too expensive for Africa. Savings were realized and the intention was to set up a business system that would be mainly run by African entrepreneurs.” [83, p. 70]
Iterative	29% (10/34)	“Overall, the [frugal] innovations are not just about providing low-cost care for underserved populations. Rather, they drive value by [...] focusing on continuous improvement” [15, p. 1916] / “Another factor is the organization’s short-term orientation stimulating a faster initiating process where employees tend to apply a ‘trial-and-error’ approach, rather than a long range project planning.” / “employees are highly encouraged to experiment novel methods and approaches concerning the production processes.” (see [20, p. 243, p. 242]) / “Multiple design iterations might be warranted even after adopting a rigorous design process to iron out all the weak spots of a frugal product as is evidenced by the reported malfunctioning in the first generation Tata Nano [...] which has been rectified in the latest version” [61, p. 50]/ “So, more often than not, frugal innovation comes from the cumulative effect of implementing small-scale ideas over prolonged periods of time. It is a process that encompasses the acts of numerous individuals, not only the original inventors but also the producers, consumers, and middlemen that transmit and operationalize the innovations, making them acceptable to society [45, p. 4]
Simplified	24% (8/34)	“Complexity reduction can also be observed in the innovation process leading to a frugal outcome, as implied by this quote of a manager at Indústria Fox: ‘The approach is basically to reduce the length of the value chain and carry out all steps autonomously, and thus we are competitive regarding manufacturing and overall costs.’ (Indústria Fox, Manager)” (see [20, pp 243])
Done in collaboration with other stakeholders	21% (7/34)	“We have collaborations with more than 100 local Indian suppliers who manufacture critical vehicle components, modules and integrated systems for us. Alliances with our suppliers and leveraging their expertise has enabled us to develop practical solutions for addressing some of the sturdy challenges we faced for innovating vehicles for the Indian market.” [73, p. 17], “Frugal innovations are particularly successful when local suppliers are integrated into the value chain” [44, p. 25], “In addition, frugal innovation relates to what has been conceptualized as ‘polycentric innovation’ and designates the global integration of specialized research and development capabilities across multiple regions to create novel solutions that no single region or company could have completely developed on its own” [83, p. 62] “[...] the value chain is characterized by cooperation, partnerships and NGO involvement” [56, p. 19]
Flexible	18% (6/34)	“They [innovations for process improvement] are adaptive and able to expand and be scaled up, in both size and purpose—which magnifies their impact.” [15, p. 1916] “The flexibility and timeliness of RO entrepreneurs’ maintenance services was regarded valuable to the end users. ‘Because also he came on Sunday, we had a problem with our motor, he came on Sunday and he fixed. And we were not left without water for more than 5 h’. The entrepreneurs are cognizant of this.” [7, p. 6]
Self-sustaining	6% (2/34)	“[...] ‘We thought: If you have nothing – and I mean literally nothing – what do you need to conduct the [healthcare] analysis? So, we started with a zero-environment in mind: no electricity, no water, and no educated staff.’” [89, p 7]



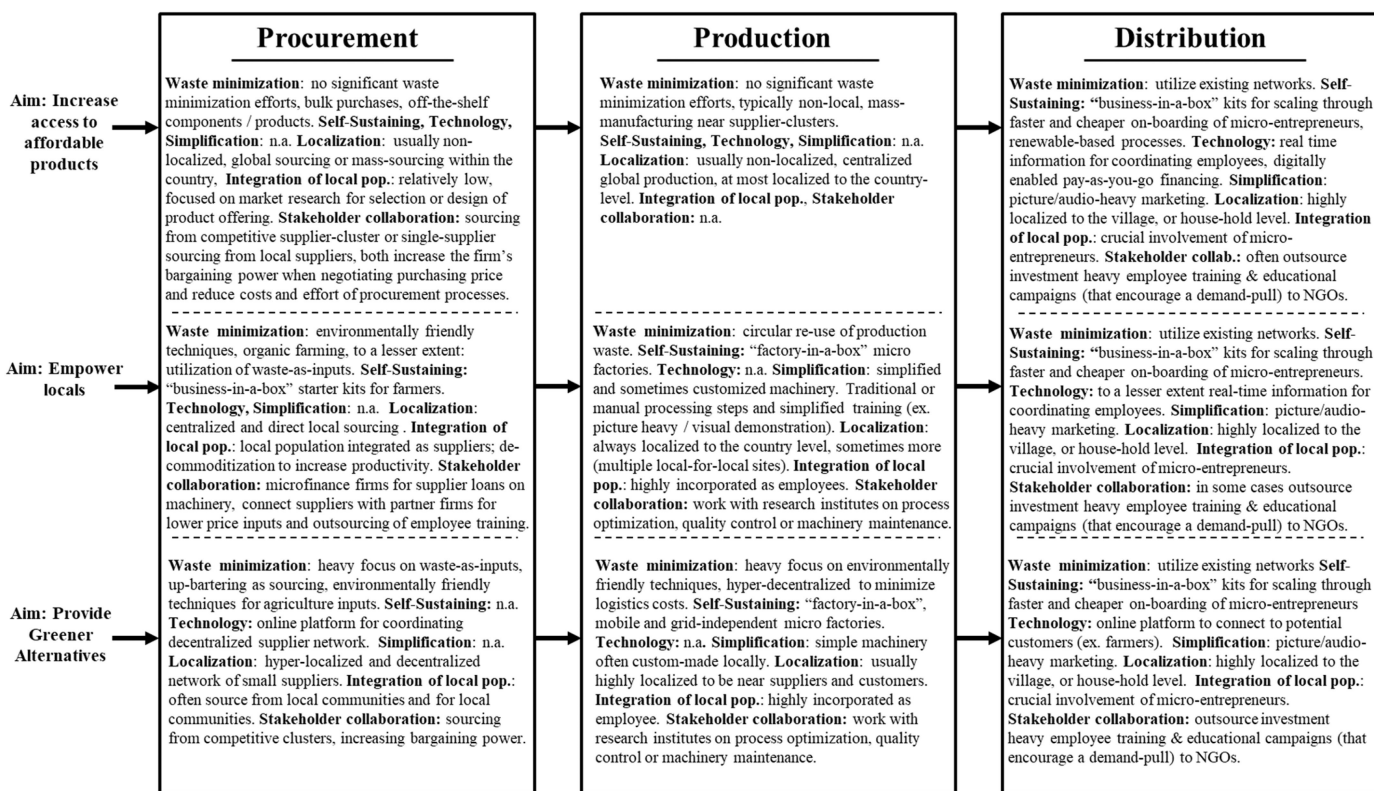


Fig. 6. Overview of characteristics at each stage of the supply chain.

identified characteristics can be configured to achieve frugality within each supply-chain stage of firms at the bottom of the pyramid.

#### IV. EMPIRICAL EXPLORATION OF FRUGAL PROCESSES

In this section, we explore how firms can best configure the previously identified process characteristics in order to react to resource constraints and achieve frugality at each stage of the supply chain, as well as overall, at a supply-chain level.

##### A. Achieving Frugality at Each Stage of the Supply Chain

In the following section, we draw 9 firms out of our 87 case studies, in order to illustrate how they achieve frugality differently at each stage of the supply chain. We show that companies choose different avenues for targeting resource constraints, depending on their primary motivation; increasing access to affordable products, fostering empowerment, or providing greener alternatives. The results are summarized in Fig. 6.

1) *Ventures Aiming to Increase Access to Affordable Products:* Frontier Markets is a social enterprise established in 2011, operating across multiple states in India. The venture aims to connect low-income rural families to a wide range of affordable consumer durables, such as solar lamps, home appliances and basic smartphones. With the goal of providing "Products for the People" [49], over 80% of the firm's customers earn under 2.5 USD a day [27]. The company has scaled significantly since

its establishment, with over 5000 employees in direct contact with 550 000 households, and aims to expand to two million households by the year 2021 [22].

The company does not design the products it sells in-house. Instead, it achieves competitively low prices per unit by rigidly selecting suppliers that meet customers' quality expectations at a competitive price-point and purchasing finished products in bulk. Suppliers are often multinational firms such as Hindustan Unilever or Samsung [54]. Distribution processes, particularly last-mile deliveries, are the core of the company's supply chain [4]. Distribution is designed around a hub-and-spoke network of thousands of microentrepreneurs that work on a commission basis to push product sales in their area, either door-to-door or through demonstrations in local markets. Each of the microentrepreneurs is associated with one of the company's local branch offices. These offices are located within no more than 5 km of villages they serve, in order to achieve an average delivery-time of under 48 h [54]. Efficient use of the resources in this vast network is achieved through the digitization of order management, as well as real-time communication and reporting through a mobile application [54]. Additionally, the company collaborates with the Princess Diya Kumari Foundation to provide entrepreneurial training to its numerous field employees.

The second company is Nuru Energy, a social enterprise established in 2008, based in Rwanda but operating across several countries. Aimed with the mission "to bring clean energy to every village in the world" [52], the venture specifically targets

households earning less than 1.5 USD a day [52]. Households in such deep poverty can find it difficult to gather the upfront costs of purchasing even stand-alone products, such as solar lamps. Instead, the venture sells multifunctional light bulbs. When their power runs out, the bulbs can be recharged for 0.2 USD by the venture's entrepreneurs, using a uniquely designed machine called PowerCycle, which converts energy from manual cycling into usable energy [52]. Since its inception, the venture has scaled to employ 1000 employees who serve 120 000 customers.

The company designs all its products in-house. Raw material is primarily sourced from key suppliers in China and assembly is carried out centrally in China, with a single, partner factory [72]. Distribution processes are centered around networks of microentrepreneurs that are encouraged to develop franchises of the brand and promote sales on a village level. In addition to the one-off sales of the original light bulbs to customers, the more long-term revenue stream is based on the revenues from bulb recharging services. In order to scale quickly, the firm lends the PowerCycle machines to the entrepreneurs at a significantly reduced price, so that they are then able to establish recharging stations in their local region. The firm ensures a cost-effective management of the numerous recharging stations by integrating mobile payments and remote locking of the recharging machines if the payments by the microentrepreneurs are not received.

The third company is Wana Energy, a socially oriented enterprise established in 2008, operating across Uganda. The company provides clean-cooking solutions based on liquefied petroleum gas to rural, low-income families. It carries out last-mile delivery of the gas cylinders, and also provides any supplementary products necessary, such as cook-stoves. Customers with a daily income of under two USD can also pay with agricultural produce. The company has a client base of 15 000 households [55], [86].

Wana sources its cook-stoves from a single-supplier partnership with Okapi Trading Limited, enabling a discounted selling price on the original wholesale price [25]. The biogas is processed in a centralized, large-scale filling facility, in which the company recently invested 300 000 USD. Last-mile delivery is carried out by the company's own logistics fleet, with motorbikes as the main mode of transport. The gas cylinders that are sold to customers are typically equipped with remote monitoring technology that automatically alerts Wana when the tank is running low. Customers are also able to pay via mobile payments, in a pay-as-you-go model [86]. The company also uses a pay-as-you-go model to introduce a specialized service of access to joint community kitchens, for households that are unable to pay the upfront costs of the stove, or the ongoing costs for gas. In order to deepen their presence in rural areas, Wana has also begun developing a microfranchising network of women to push sales deeper in rural regions [86].

2) *Ventures Aiming to Foster Local Empowerment*: Pride Pads is a social enterprise established in 2016, based in Ghana. The venture aims to empower young girls and women in rural, low-income communities and destigmatize menstrual health. They provide access to affordable but high-quality sanitary pads and raise awareness through educational campaigns on hygiene management. Since its establishment, the company has sold

702 000 sanitary pads and created an almost exclusively female employee-base of over 160 people [88]. The company's sanitary solutions were developed completely in-house. In its sourcing processes, PridePads very actively supports female farmers that are selected to cultivate banana (fiber) and cotton, which are the key raw materials used for the product. Further processing of the fiber is carried out in a small, central factory in Accra, where the company hires and trains women from impoverished background in the manufacturing processes [64], [88]. The production is largely based on labor-intensive and simple processes. PridePads collaborates with The Gratis Foundation for carrying out machine maintenance and quality control [64]. The firm promotes local sales in weekly occurring local markets, as well as through additional education programs, which they themselves organize and run across the country.

The second venture is the Bamboo Bikes Initiative, a social enterprise established in 2009, operating across Ghana. The company aims to battle local unemployment by creating jobs for women, who build affordable but high-quality bicycles from bamboo. The company has a direct employee base of 35 local employees [38]. The unique bicycle design was developed in-house [9]. The venture hires, trains and supports local farmers to grow its main raw material, bamboo, in the company's own, central farm. For each bamboo that is harvested, the company plants at least four more [21]. BambooBikes trains employees in the bicycle manufacturing and assembly processes, which are labor-intensive and focused on artisanal skills. Additionally, trained employees are encouraged to also set up an independent franchise workshop in their local area, to generate local employment and grow sales [78]. To further increase affordability of the end product, the company cross-subsidizes the bicycles sold locally through collaboration with firms that are interested in advertising their brand on the bicycle chassis [28].

The third venture is Lagazel, a social enterprise established in 2015, operating in Burkina Faso, Senegal, and Mali. The company deliberately opted for local job creation and was the first firm to produce solar-lamps in Africa on an industrial scale. Since its establishment, the company has reached an active customer-base of over 56 000 people, and production capacities of 150 000 lamps annually [19]. Most other firms from the energy sector in our database chose to source or assemble their products centrally in China, which is a competitive global hub for solar components [11]. Instead, Lagazel focuses on designing and manufacturing their solar products in-house and in Africa. Components are sourced from French suppliers, and the assembly takes place in a central factory in Burkina Faso. Manufacturing relies on labor-intensive, rather than automated, assembly. In addition to its central factory, the company has also developed unique microfactories from refurbished containers, dubbed "L-BOX." These are mobile and electricity-grid independent production units that are deployed by Lagazel as satellite factories in multiple locations. Each of the deployed units requires labor-intensive assembly and can produce at a maximum capacity of 200 000 solar lamps annually. By deploying satellite units, the company also aims to address material waste issues occurring at the end of the solar lamps' life cycle [19]. Lagazel's cooperates with the nongovernmental

organization *Entrepreneurs du Monde* to identify and train over 100 female microentrepreneurs to promote local product sales. The company also offers cross-subsidization based financing schemes.

3) *Ventures Aiming to Provide Greener Alternatives*: *GreenBio Energy* is a social enterprise established in 2011, based in Kampala, Uganda. The company's primary focus is promoting greener sources of energy by providing a variety of energy-efficient products under the brand "Briketi." For example, briquettes produced from recycled material or supplementary products such as cook-stoves. *GreenBio* has a customer base of roughly 560 000 clients across Uganda [29]. The company procures bio-waste from a very wide network of people in local communities, as well as from a network of 100 women waste collectors. The company processes the waste in its own, central factory. The process is labor-intensive, but the company has also developed and manufactured its own sturdy and simple machinery line, in order to increase their manufacturing output. *GreenBio* was forced to design and even produce the machines in-house due to its inability to purchase the more expensive alternatives that are readily available in the market. The components for the machines are also locally sourced [29]. The firm is working toward decentralizing its production, and aims to develop a hyper-decentralized network through a model they dub "Pamoja" ("together" in Swahili). The model involves scaling through replication, by training entrepreneurs across communities to carry out the manufacturing processes, and creating independent satellite enterprises that sell their output under the umbrella brand "Briketi" [29]. The company's custom-made frugal machinery enables each production unit to process up to 2 ton of inputs per day. The firm closely collaborates with research institutes for continuously optimizing their manufacturing (the Norwegian nongovernmental organization *Design Without Borders*) or for surveying potential customers with the aim of designing more effective distribution channels (the Massachusetts Institute of Technology's *D-Lab*) [31]. In addition to the scaling through replication, the company also developed a network of independent microentrepreneurs to push sales locally in communities.

*Safi Organics* is a social enterprise established in 2015, based in Nairobi, Kenya. The company aims to provide greener alternatives to existing agriculture inputs available in Kenya, which can cause severe environmental issues like increased soil acidity. The company produces and sells *Safi Sarvi*, a carbon-negative fertilizer that has quickly become a well-known national brand [69]. *Safi* sources rice husk and farm waste that would otherwise be burned from a very wide network of farmers, at 30 USD per ton. Using a simple but effective organic technique that was developed in collaboration with the Massachusetts Institute of Technology, the company transforms the waste into agricultural inputs [68]. Rather than starting with a central production approach and aiming to increase manufacturing locations over time, the company originally designed its manufacturing network with a hyper-decentralized approach in mind. Manufacturing takes place in multiple locations. Through labor-intensive processes, each production unit is able to process a maximum of 4 ton of inputs daily, with an overall processing

time of 6 h per batch. The company strives for each production unit to supply an area of no more than a 100-km radius. This decentralized approach was designed to significantly reduce the high logistics markup costs from exporting material, reduce the high transportation costs to rural areas, as well as enable a very high level of localization, with processes customized at times even to a village level. The transformed inputs are then sold back to the farmers' network or sold through local sales agents that push the product [68].

The third venture is *Ekasi Energy*, a social enterprise established in 2016, based in Stellenbosch, South Africa. The company aims to provide greener cooking alternatives, as open stove cooking and similar methods facilitate deforestation and adverse health effects from smoke inhalation. The company provides biomass-based pellets, as well as supplementary products such as fan-assisted gasifier stoves. *Ekasi* develops their supplementary products such as cook-stoves with the research institute *DR TLUD* [23]. The firm sources biomass waste that would otherwise be discarded from a wide network of individuals from local communities. Their manufacturing is carried out in a decentralized network of microfactories designed from refurbished containers, dubbed "FabTainers" [76]. The *FabTainers* are automated production units that can process up to 400 kilograms of inputs per hour at full capacity. They are deployed in multiple locations and are able to operate independent from the main electricity-grid, in order to ensure production does not halt during power outages. *Ekasi* developed a network of microentrepreneurs to push the sales of their products, and works in collaboration with the nongovernmental organization *iKhayalami Market* in order to identify individuals in the respective local communities to target and train as employees.

### B. Achieving Frugality at a Supply-Chain Level

In the previous section, we introduced nine illustrative examples of firms in our database. We described how ventures with different primary goals react differently to resource constraints at each individual stage of the supply chain. However, because the outputs of one stage of the supply chain are the inputs of the next, how firms choose to overcome constraints in one stage of the supply chain is strongly interconnected with their approach in the other stages. Therefore, in this section, we analyze our findings on a supply-chain level. We identify three archetypes of frugal supply chains that firms can choose to adopt, depending on their primary aim, in order to achieve frugality at the supply chain level.

1) *Archetype I: Postponing Decentralization*: The first archetype was typically adopted by firms driven by the motivation to increase access of individuals to affordable products. For example, in their website, our previously discussed firm, *FrontierMarkets*, notes that "despite the demand [...] there was a gap: companies simply were not getting their products into the hands of last mile customers. There was a Last Mile access gap—and *Frontier Markets* was launched to close it" [54]. Companies inclined toward such a mission statement often adopt a supply-chain structure that aims to capitalize on traditional economies of scale for as long as possible, in order to achieve

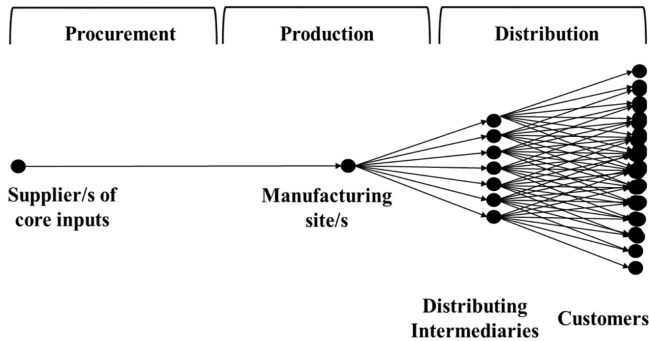


Fig. 7. Postponing decentralization: An illustrative supply-chain structure.

lower manufacturing costs per unit. They conserve their financial resources for building a powerful and highly decentralized distribution network, aimed at reaching vast numbers of potential consumers (see Fig. 7).

Sourcing of core inputs and raw material is primarily focused on achieving low price points. In most cases, these price points were achieved through buyer–supplier relationships that resemble more traditional approaches. For example, many firms carry out global sourcing from regions of known clusters for a certain component. By doing so, they capitalize on the high bargaining power of buyers in such markets due to increased rivalry amongst the suppliers while simultaneously enjoying the very high levels of technical know-how and subsequent quality for said component. Alternatively, low price points were also achieved by single-sourcing key inputs from one key (and typically more local) supplier. Firms then build a relationship with their core supplier, which enables them to request significant discounts on purchase prices. Directly connected to their procurement strategy, companies in this archetype typically adopt a centralized approach to production. In most cases, assembly is carried out in a factory located at the country from which the main components are sourced, and then transported via large shipments into the country of the target market.

Unlike the relatively centralized procurement and manufacturing, distribution processes in this archetype are highly decentralized and oriented toward pushing products down the supply chain and to the final consumer, with the understanding that the “First to market with an aggressive push will create [customer] loyalty” [87]. Distribution is based around a very large network of microentrepreneurs that promote products in their local areas, often conducting door-to-door sales. The costs of this vast network are kept down in two key ways. First, the microentrepreneurs often work on a commission basis, thus significantly reducing labor costs. Second, the decentralized network is strongly backed by technology-enabled processes, such as remote control of machinery, mobile payments, and mobile-based applications for employee management, all aimed at reducing the transaction costs and costs of coordination that are typically associated with large decentralized networks.

2) *Archetype II: Balancing Investment Costs and Productivity*: This second frugal supply-chain archetype was typically adopted by firms aiming to foster empowerment. For example, the founder of the company Eco-Shoes, Mable Suglo, noted in

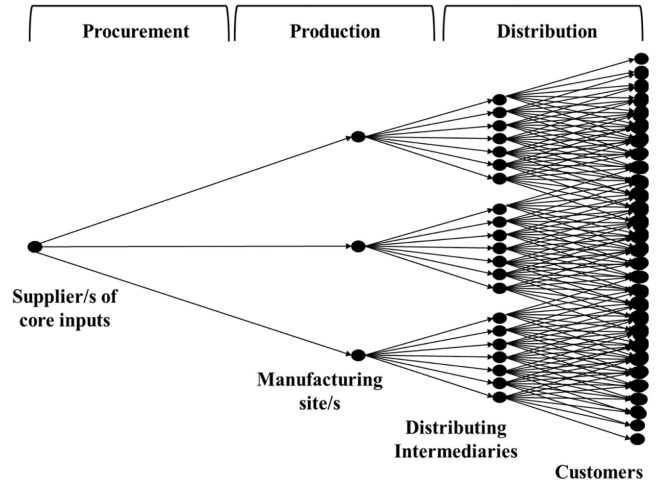


Fig. 8. Balancing costs: An illustrative supply-chain structure.

an interview that she established the company after witnessing a disabled beggar humiliated and isolated in his hometown. She said “[...] I just walked up to him, and I asked him, if he could get a job that would pay better than begging, would he be ready to work? And he said yes” [41]. Companies with such a mission would clearly be less interested in designing their supply chain to reduce costs through the economies-of-scale benefits of global sourcing or nonlocal production that are prevalent in Archetype I. However, developing economies-of-scale through a similar supplier base and manufacturing capacities in their local region would require investing a significant amount of resources. Therefore, these firms face a delicate balancing game, whereby they must decide on a sweet spot between investing their (often lacking) funds for developing local capabilities and the subsequent gains of higher productivity as well as achieving their mission of local empowerment (see Fig. 8).

Key raw materials that are necessary for the products are usually grown by the company itself in a central location, in the case of organic inputs, or otherwise, sourced from very few suppliers in close proximity to the firm, which the firm then diligently supports. This “decommoditization” of suppliers both furthers the firm’s empowerment mission and ensures the quality of inputs, as well as the efficient use and reuse of the limited resources across the firm’s supply chain. For example, the company “Papyrus Reeds, Our Future Hope” repurposes the organic by-products produced during its manufacturing processes by turning it into fertilizer that they then provide to their local suppliers.

In direct relation to their procurement approach, firms subscribing to this archetype aim to build enough manufacturing capacity locally in order to be able to capitalize on economies of scale. However, in order to build such capacities at significantly less investment costs, they often rely on labor-intensive and simplified manufacturing. Simplification takes place either in the manufacturing steps themselves, in the simplification of employee training, or, alternatively, by utilizing simple and rudimentary machinery. Simplification of processes contributes

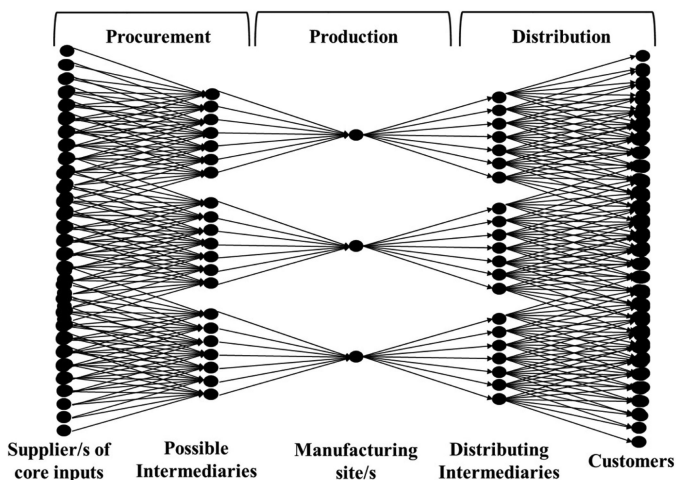


Fig. 9. Hyperlocalization: An illustrative supply-chain structure.

to economic performance by enabling firms to expand production capacity despite constraints such as a poorly educated workforce. Additionally, this simplification also enables firms to provide employment opportunities to individuals who would be difficult for firms to employ otherwise, in a nonsimplified process. For example, some companies deliberately make their production accessible to employees with certain physical disabilities, by simplifying employee training. Finally, as manufacturing is carried locally and in-house, firms have a high degree of control over their production processes. Some firms utilize this control as an opportunity to initiate creative solutions for lowering the end price points even further. For example, firms collaborate with other companies to brand their products during the manufacturing stage with the partner company's logo, and utilize the funds from this collaboration in order to cross subsidize their own products. Distribution in this approach bears a great resemblance to that described in the previous archetype.

3) *Archetype III: Hyperlocalization*: The last approach was typically adopted by firms interested in providing customers with greener alternatives to existing solutions. PBK Waste Solutions Pvt. Ltd., a venture with such a mission, articulated that their approach is "[...] to create a large impact through a large number of people doing small actions." This greatly characterizes the resulting supply-chain archetype of likeminded firms. Companies with this mission typically do not attempt to utilize cost reduction through economies of scale at any stage of their supply chain. Rather, they aim for a hyperdecentralized local-for-local network that is focused on reducing logistics markups and transportation costs (see Fig. 9).

In procurement, firms often design their product offering around waste as a core input. Sourcing activities revolve around reducing procurement costs by sourcing materials considered to be waste, sourcing through engaging in up-bartering with individuals at the bottom of the pyramid, or alternatively, if the company grows its own raw material, a strict emphasis on techniques that reduce environmental damage and require less environmental resources (such as water). Unlike the previous two archetypes, sourcing is typically carried out from a vast

and decentralized network of microsuppliers. Often, these are individuals or households in multiple communities. In order to ensure maximum efficiency in the resource allocation and utilization of this vast decentralized network, firms often implement technology-enabled processes. For example, Waste Ventures India provides an online platform for connecting urban households that are interested in a convenient disposal of their recyclables with a large network of independent waste pickers. The last mile logistics of this exchange is coordinated completely online. The recyclables are picked up and then transported to the company, where they are consolidated and processed into the final product. The technology-enabled scheduled pick-up appointments and instant digital payment enable a seamless process and a significantly more cost-effective potential of scalability.

Production is closely linked with the procurement approach of these firms and relies rather heavily on scaling through replication rather than through traditional economies of scale. As discussed in the previous archetype, freeing up funds for building capacities, at times even for a single facility, can be challenging to firms who insist on producing locally. Therefore, in order to be able to develop a network of factories, the production units themselves must require low investment costs and be highly cost effective. An interesting solution firms use to achieve this is utilizing a "production-in-a-box" approach. This approach involves refurbishing mobile units, for example, shipping containers, into "mobile factories." Multiple microfactories then form a highly decentralized production network. These microfactories are designed to be self-sustaining and run as independently as possible. For example, each microfactory is less dependent on factors such as electricity grid connection. Therefore, this approach allows for more freedom in choosing the optimal locations for the microfactories based on proximity to demand (potential consumers) or supply. This results in a manufacturing network that is significantly less susceptible to fluctuations in demand or supply. For example, an unexpected regional shortage in the raw materials necessary for production or a shortage in the labor force available in the region can be overcome by dynamically changing the locations of the microfactories in the network.

## V. DISCUSSION AND OPPORTUNITIES FOR FUTURE RESEARCH

In this section, we discuss potential theoretical links between our findings and existing literature on supply-chain management, frugal innovation, and literature on markets at the bottom of the pyramid in general. We identify opportunities for future research at the intersection of these fields.

### A. Research Opportunities at Each Stage of the Supply Chain

1) *Procurement Under Resource Constraints*: There are many implicit connections between approaches noted in frugal innovation literature and established Lean Manufacturing principles and practices proposed in operations management literature. For example, Bhatti *et al.* [15, p. 1916] alluded to "leaner" processes through continuous improvement. In other cases, articles even explicitly refer to Lean Manufacturing as a frugal process [62], [77]. However, the extent to which approaches

such as lean optimization are possible in bottom of the pyramid markets has not yet been explored in detail. Existing research on operations at the bottom of the pyramid has stressed that the unique characteristics at the bottom of the pyramid significantly differ from markets in formalized settings and companies need to operate differently in bottom of the pyramid markets [14], [93]. Resource constraints, as well as institutional and infrastructural constraints, could cause significant hurdles in the adoption of conventional lean management approaches, such as one-piece flow and just-in-time supplier deliveries. However, research on operations at the bottom of the pyramid has not yet explicitly studied whose modifications to the established lean methods are necessary and why.

One example for the potential of cross fertilization between lean optimization and achieving frugality at the bottom of the pyramid relates to the core understanding of what constitutes as “waste.” Most articles addressing frugal innovation in bottom of the pyramid markets refer to “waste” as environmental damages or unused materials. However, Lehner *et al.* [44], who studied frugal innovation in contexts outside the bottom of the pyramid, described waste as the following: “A comprehensive understanding of the customer must be established and, in particular, the willingness of customers to pay. It is just as important to determine what the customer does not want to pay for” [44, p. 25]. This greatly correlates with the understanding of waste in classic lean literature [72]. In lean management, “waste” is defined with the end customer in mind and generally understood as all aspects of a process that a customer would not be willing to pay for [90]. Therefore, if we adopt the understanding of classic lean literature to what constitutes waste, research must first gain a solid grasp on what is considered valuable to bottom of the pyramid consumers. However, research on operations at the bottom of the pyramid, as well as frugal innovation, rarely take the perspective of individuals and tend to focus on firms as the unit of analysis. Some exceptions are von Janda *et al.* [85] who take the perspective of consumers at the bottom of the pyramid in their study of useful product features.

We argue that frugal innovation can play a meaningful role in bridging between lean management and research on operations at the bottom of the pyramid, by studying frugal processes through adopting an understanding of waste centered around the customer. Based on the previous discussion, we pose the following questions for further research.

- 1) What are the challenges and potential of implementing lean management principles in operations at the bottom of the pyramid?
- 2) How can lean management tools be adopted in order to be successfully applied to the operations of firms at the bottom of the pyramid?

2) *Manufacturing Under Resource Constraints:* One of the more interesting patterns discovered in our empirical investigation was the unique approach of “production-in-a-box,” which involves increasing manufacturing capacity by designing a highly decentralized network of self-sustaining, micro-sized production units powered by renewable energy rather than the central electricity grid. There is relatively very little work focused on manufacturing in bottom of the pyramid markets [14].

Historically, manufacturing has proven to be one of the most disruptive arenas for innovation. Current mainstream approaches to production systems, such as Lean Manufacturing, though standard-practice today, were highly innovative and revolutionary at their inception. For example, Lean Manufacturing emerged in light of the resource-constrained realities of the automotive sector in post-world-war Japan, and revolutionized mainstream product approaches at the time, which centered around mass production. Similarly, Ford’s Model T and the invention of the industrial assembly line had also revolutionized the manufacturing practices considered commonplace before them. With the Model T, Ford aimed to “build a car for the great multitude” [63] and make a product that was previously only available to a select few, accessible to a wider and less financially well-off segment of society. As innovation in manufacturing often emerged from a need to overcome resource constraints, we argue that research on manufacturing operations in resource-constrained settings will not only further our understanding of operations at the bottom of the pyramid, but also introduce new and innovative manufacturing approaches to mainstream operations literature.

Manufacturing approaches in bottom of the pyramid settings could also be transferrable to companies in developed markets, where consumer dynamics increasingly demand flexibility and sustainability from company operations [26]. Research on frugal innovation has already begun to address the flow of reverse innovation from the bottom of the pyramid to developed economies in the context of product innovation. We argue that there is also great potential for reverse process innovation. More specifically, research at the intersection of frugal innovation and supply chain can identify and further develop completely new approaches to cost-effective and sustainable manufacturing and logistics systems. Based on the previous discussion, we synthesize and pose the following question:

- 1) To what extent can innovative frugal processes developed for bottom of the pyramid markets be transferred and implemented by companies in developed economies?
- 3) *Distribution Under Resource Constraints:* Technology-enabled processes were dominant particularly in the distribution of all three supply-chain archetypes. However, technology-enabled processes are hardly focused on in existing frugal innovation literature. One reason for this could be related to the skewedness of geographic representation in literature [2]. Different geographic settings significantly change market dynamics and opportunities, and by extension also the topics literature focused on them studies. For example, China is currently a world leader in terms of rural internet access and mobile phone ownership and has a well-developed e-commerce market [48]. This could make it an interesting context for the study of technology-enabled frugal processes. Liu *et al.* [48] began to address this opportunity and look into digitally enabled frugality in the e-commerce industry in China. In our empirical investigation, there are many interesting cases of technology-enabled processes particularly in the decentralized stages of the supply chain. For example, companies with a highly decentralized supplier network often use mobile applications to manage their upstream operations. Similarly, companies

with a highly decentralized distribution network often utilize technology to bring down the costs of coordination for their microentrepreneur network. In general, integrating technology in processes could greatly assist in scaling-up operation while maintaining or reducing distribution costs, which tend to be very high for firms at the bottom of the pyramid [75]. Therefore, we synthesize and pose the following research questions.

- 1) What are the key operational challenges impacting cost-effective distribution of frugal products at the bottom of the pyramid?
- 2) How can firms overcome infrastructural, institutional, and resource constraints at the bottom of the pyramid by integrating technology within their operations?

### B. Research Opportunities at a Supply-Chain Level

In this section, we outline two avenues for future research at a supply-chain level. The first avenue relates to the incorporation of a time dimension to future work. Bottom of the pyramid markets are typically highly dynamic, due to high unpredictability of certain elements; consumers are often unable to predict their future cash flow [39] and firms are often unable to predict supply-chain disruptions, for example, an infrastructure breakdown. As articulated by the founder of FrontierMarkets, "Every time you think you've seen it all, something else surprises you. For me, I learned that the places where we're working are massively chaotic and unpredictable" [22]. In this article, the data represented a screenshot of the companies' processes at a specific point in time. This rendered the study of the time-related characteristics identified in the literature, namely their iterative nature and high flexibility, not possible. Additionally, we were unable to provide insights on whether the manner in which characteristics are configured by firms changed over time, or subsequent insights on the extent to which a firm's choice of supply-chain archetype changes over time. Based on this, we call for longitudinal studies that address the following research question.

- 1) To what extent does the strategic supply-chain design of firms at the bottom of the pyramid evolve over time and how does this impact their operational performance?

The second avenue of research relates to the environmental sustainability of frugal innovation. Frugal innovation, particularly frugal products, are often assumed to be environmentally sustainable [67]. However, the prevalence of environmentally friendly practices in the later stages of the supply chain was significant only in Archetype II and Archetype III (firms aiming at "fostering local empowerment" and "providing greener alternative"). This raises concerns on the environmental impact of companies offering frugal products, and particularly, on the subsequent net impact of their supply chain as a whole. Prabhu [57, p. 15] noted the importance of a system approach to address the impact of frugal innovation on a broader economy level, stating that "Attempts to reduce material use in one part of a complex system might only result in increasing material use in another."

Therefore, there is great value in looking into environmental waste minimizing approaches across entire supply chains in bottom of the pyramid markets. This could be achieved

through cross fertilization between frugal innovation literature and research in the field of "green" or sustainable supply-chain management, which is heavily focused on the measurement of environmental impact [92]. Based on the previous discussion, we synthesize and pose the following questions.

- 1) What is the environmental impact of frugal products when taking a system perspective?
- 2) To what extent can best practices from existing literature on sustainable supply-chain management be integrated to minimize environmental waste across supply chains at the bottom of the pyramid?

## VI. CONCLUSION

The bulk of previous research on frugal innovation focused on the unique characteristics of frugal products, their relevance in bottom of the pyramid markets, or in a global setting, regardless of context. Frugal products tend to be cheaper, more functional, or focused on basic needs, yet they provide an adequate answer to customer requirements. However, no previous research has, to the best of our knowledge, consolidated similar knowledge specifically for frugal processes. By utilizing a systematic literature review that explicitly focuses on processes, as well as an empirical investigation of ventures from multiple industries operating in resource constrained environments, we show how resource constraints are felt across entire supply chains, not only how they impact companies' end product.

We aim to contribute to frugal innovation literature by consolidating existing knowledge on frugal processes. We show how the general trends in frugal innovation thus far have influenced our understanding of frugal processes, and delineated three distinct viewpoints. The first conceptualization of frugal processes is focused on frugal products and their development. The second conceptualization extends this view and stresses the importance of addressing all stages of the supply chain, not only product development processes. Third, frugal processes can be viewed as the outcome, or the innovation itself, rather than as a means to an end; for example, innovative frugal logistics systems and business models. Additionally, we identify the key characteristics of frugal processes. Frugal processes, as portrayed in literature, are the following:

- 1) minimal in waste creation;
- 2) technology enabled;
- 3) simplified in comparison with their nonfrugal counterparts;
- 4) self-sustaining;
- 5) localized;
- 6) carried out in collaboration with other stakeholders;
- 7) often carried out specifically by the local bottom of the pyramid population;
- 8) iterative and focus on continuous improvement; as well as highly
- 9) flexible and easily adaptable.

Our empirical investigation into the operations of resource constrained firms at the bottom of the pyramid shows how these firms can configure the identified characteristics in order to achieve frugality at each stage of the supply chain. Based on a rigid cross-case analysis, we develop three possible archetypes

for achieving frugality on a supply-chain level and note which of these archetypes work best for firms with different primary goals and motivation. As such, our findings can greatly assist the consequent transfer of best practices across different industries and contexts. In particular, findings of this research can be of interest to practitioners dealing with uncertainty on how to design their operations such that they support their mission statement while still minimizing the economic costs of their decisions. More broadly, the findings of this article suggest that there is great potential in transferring the crux of attention in the literature from frugal innovation's outcomes to its processes. By providing multiple research questions for further exploration of the process echelon of frugal innovation, this article aims to open up a more robust discussion in the frugal innovation literature on the tradeoffs between economic, social, and environmental performance of companies engaging in such innovation.

## REFERENCES

- [1] N. Agarwal and A. Brem, "Frugal innovation—past, present, and future," *IEEE Eng. Manage. Rev.*, vol. 45, no. 3, pp. 37–41, Jul.–Sep. 2017.
- [2] N. Agarwal, M. Grottko, S. Mishra, and A. Brem, "A systematic literature review of constraint-based innovations: State of the art and future perspectives," *IEEE Trans. Eng. Manage.*, vol. 64, no. 1, pp. 3–15, Feb. 2017.
- [3] A. Agnihotri, "Extending boundaries of blue ocean strategy," *J. Strategic Marketing*, vol. 24, no. 6, pp. 519–528, 2016.
- [4] Marion Allet, "Energy Entrepreneurs: An innovative model to reach the last mile," *Journals.openedition.org*, 2016. Accessed: Apr. 21, 2020. [Online]. Available: <https://journals.openedition.org/factsreports/4211#ftn2>
- [5] M. A. Altamirano and C. P. Van Beers, "Frugal innovations in technological and institutional infrastructure: Impact of mobile phone technology on productivity, Public Service Provision and Inclusiveness," *Eur. J. Develop. Res.*, vol. 30, pp. 84–107, 2018.
- [6] Anderson and C. Markides, "Strategic innovation at the base of the pyramid," *MIT Sloan Manage. Rev.*, 2007. Accessed: Apr. 11, 2020. [Online]. Available: <https://sloanreview.mit.edu/article/strategic-innovation-at-the-base-of-the-pyramid/>
- [7] L. Annala, A. Sarin, and J. Green, "Co-production of frugal innovation: Case of low cost reverse osmosis water filters in India," *J. Cleaner Prod.*, vol. 171, pp. S110–S118, 2018.
- [8] C.-C. A. Asakawa and C. Annique Un, "Frugality-based advantage," *Long Range Planning*, vol. 52, no. 4, 2019, Art. no. 101879.
- [9] K. Assaël, *Ideassonline.org*. Accessed: Apr. 11, 2020. [Online]. Available: <http://www.ideassonline.org/public/pdf/BambooBikesENG.pdf>
- [10] J. Baekelandt, "Total vaginal NOTES hysterectomy: A new approach to hysterectomy," *J. Minimally Invasive Gynecol.*, vol. 22, no. 6, pp. 1088–1094, 2015.
- [11] D. R. Ball, X. Sun, and C. Pollock, "The new solar system," Stanford Law School, Stanford Graduate School Bus., Stanford, CA, USA, 2017.
- [12] F. Belkadi *et al.*, "Modularity as a support for frugal product and supplier network co-definition under regional market constraints: A mirroring hypothesis application," *Int. J. Prod. Res.*, vol. 56, pp. 6575–6590, 2018.
- [13] A. Bencsik, R. Machova, and Z. Tóth, "Cheap and clever—symbiosis of frugal innovation and knowledge management," *Problems Perspect. Manage.*, vol. 14, pp. 85–88, 2016.
- [14] J. C. Bendul, E. Rosca, D. Pivovarov, and E. Bendul, "Sustainable supply-chain models for base of the pyramid," *J. Cleaner Prod.*, vol. 162, pp. S107–S120, 2017.
- [15] Y. Bhatti *et al.*, "Global lessons in frugal innovation to improve health care delivery in the united states," *Health Affairs*, vol. 36, pp. 1912–1919, 2017.
- [16] Y. A. Bhatti *et al.*, "The search for the holy grail: Frugal innovation in healthcare from low-income or middle-income countries for reverse innovation to developed countries," *BMJ Innov.*, vol. 3, pp. 212–220, 2017.
- [17] Y. Bhatti and M. Ventresca, "How can 'frugal innovation' be conceptualized?" *Jan.*, 19, 2013. [Online]. Available: <http://dx.doi.org/10.2139/ssrn.2203552>.
- [18] C. Bianchi, M. Bianco, M. Ardanche, and M. Schenck, "Healthcare frugal innovation: A solving problem rationale under scarcity conditions," *Technol. Soc.*, vol. 51, pp. 74–80, 2017.
- [19] Bonnard, "Une lampe solaire solidaire: Les enjeux—Lagazel," Lagazel, 2020. Accessed: Apr. 8, 2020. [Online]. Available: <https://www.lagazel.com/une-lampe-solaire-solidaire-les-enjeux-lagazel/?lang=en>
- [20] H.-C. Busch, T. Dauth, L. Fischer, and M. Souza, "Frugal innovation approaches to sustainable domestic energy: Two cases of solar water heating from Brazil," *Int. J. Technol. Learn., Innov. Develop.*, vol. 10, pp. 231–257, 2018.
- [21] P. Crowe, "Riding towards sustainable development, on bamboo," *Ourworld*, 2012. Accessed: Apr. 10, 2020. [Online]. Available: <https://ourworld.unu.edu/en/riding-towards-sustainable-development-on-bamboo>
- [22] V.D'souza, "How a last mile delivery startup's founder made into entrepreneur's 35U35 list," *Entrepreneur*, 2019. Accessed: Apr. 13, 2020. [Online]. Available: <https://www.entrepreneur.com/article/328862>
- [23] Ekasi Energy and SEED, 2020. Accessed: Apr. 14, 2020. [Online]. Available: <https://seed.uno/enterprise-profiles/ekasi-energy>
- [24] The Economist, "First break all the rules: The charms of frugal innovation. Special report on innovation in emerging markets," *The Economist*, pp. 3–5, Apr. 17, 2010. Accessed: Jun. 7, 2019. [Online]. Available: <https://www.economist.com/special-report/2010/04/17/first-break-all-the-rules>
- [25] SEED, "Enterprise brief: Wana Energy Solutions," 2014. Accessed: Apr. 18, 2020. [Online]. Available: <https://seed.uno/articles/enterprise-briefs/enterprise-brief-wana-energy-solutions>
- [26] K. Furst and T. Schmidt, "Turbulent markets need flexible supply-chain communication," *Prod. Planning Control*, vol. 12, no. 5, pp. 525–533, 2001.
- [27] "Frontier markets—A distribution company that ensures affordable, renewable energy products reach India's most remote communities," *Acumen*, 2019. Accessed: Apr. 16, 2020. [Online]. Available: <https://acumen.org/investment/frontier-markets/>
- [28] "Ghana's unprecedented bamboo bikes [Business Africa]," *AfricaNews*, 2018. Accessed: Apr. 12, 2020. [Online]. Available: [https://www.youtube.com/watch?v=F\\_hld8Dus7g](https://www.youtube.com/watch?v=F_hld8Dus7g)
- [29] "Yunus Social Business," *Green Bio Energy*, 2020. Accessed: Apr. 10, 2020. [Online]. Available: <https://www.yunusssb.com/portfolio/green-bio-energy>
- [30] B. Gupta and S. Thomke, "An exploratory study of product development in emerging economies: Evidence from medical device testing in India," *R&D Manage.*, vol. 48, pp. 485–501, 2018.
- [31] L. Holub and E. Saunders, "Scale-ups report from Uganda: Market research for green bio energy," MIT D-Lab, Cambridge, MA, USA, 2014. Accessed: Apr. 10, 2020. [Online]. Available: <https://d-lab.mit.edu/news-blog/blog/scale-ups-report-uganda-market-research-green-bio-energy>
- [32] *Green Bio Energy*, 2020. Accessed: Apr. 9, 2020. [Online]. Available: <http://greenbioenergy.org/products-and-services/>
- [33] M. Hossain, "Mapping the frugal innovation phenomenon," *Technol. Soc.*, vol. 51, pp. 199–208, 2017.
- [34] M. Hossain, "Frugal innovation: A review and research agenda," *J. Cleaner Prod.*, vol. 182, pp. 926–936, 2018.
- [35] M. Hossain, H. Simula, and M. Halme, "Can frugal go global? Diffusion patterns of frugal innovations," *Technol. Soc.*, vol. 46, pp. 132–139, 2016.
- [36] R. Howell, C. Van Beers, and N. Doorn, "Value capture and value creation: The role of information technology in business models for frugal innovations in Africa," *Technol. Forecast. Soc. Change*, vol. 131, pp. 227–239, 2018.
- [37] M. Hyppia and R. Khan, "Overcoming barriers to frugal innovation: Emerging opportunities for Finnish SMEs in Brazilian markets," *Technol. Innov. Manage. Rev.*, vol. 8, pp. 38–48, 2018.
- [38] Corinne Jones, "Ghana's bicycle which is creating jobs while it saves the soil," *The Guardian*, 2017. Accessed: Apr. 10, 2020. [Online]. Available: <https://www.theguardian.com/environment/2015/may/05/ghana-environment-bamboo-bicycles-seed-award>
- [39] A. Karamchandani, M. Kubzansky, and N. Lalwani, "The globe: Is the bottom of the pyramid really for you?" *Harvard Bus. Rev.*, 2011. Accessed: Apr. 11, 2020. [Online]. Available: <https://hbr.org/2011/03/the-globe-is-the-bottom-of-the-pyramid-really-for-you>
- [40] A. K. Ojha, "MNCs in India: Focus on frugal innovation," *J. Indian Bus. Res.*, vol. 6, pp. 4–28, 2014.
- [41] N. Kimani, "ECO-SHOES GHANA: Changing social perception one pair at a time," *Designers Studio*, 2017. Accessed: Apr. 7, 2020. [Online]. Available: <https://tdsblog.com/eco-shoes-ghana/>
- [42] A. Kuo, "Harnessing frugal innovation to foster clean technologies," *Clean Technol. Environ. Policy*, vol. 19, pp. 1109–1120, 2017.
- [43] F. Lan and X. Liu, "Business model transformation in digital enablement context through frugal innovation: Learning from Chinese experience," *Int. J. Technol., Policy Manage.*, vol. 17, pp. 360–373, 2017.



- [44] A. C. Lehner, C. Koldewey, and J. Gausemeier, "Approach for a pattern-based development of frugal innovations," *Technol. Innov. Manage. Rev.*, vol. 8, pp. 14–27, 2018.
- [45] A. Leliveld and P. Knorringer, "Frugal innovation and development research," *Eur. J. Develop. Res.*, vol. 30, pp. 1–16, 2018.
- [46] J. Levanen, M. Hossain, T. Lyytinen, A. Hyvarinen, S. Numminen, and M. Halme, "Implications of frugal innovations on sustainable development: Evaluating water and energy innovations," *Sustainability*, vol. 8, 2016, Art. no. 4.
- [47] C. Lim and T. Fujimoto, "Frugal innovation and design changes expanding the cost-performance frontier: A Schumpeterian approach," *Res. Policy*, vol. 48, pp. 1016–1029, 2019.
- [48] X. Liu, Y. Lin, S. Zhang, and Y. Xie, "Frugal innovation in E-commerce: A case study of Taobao," in *Proc. IEEE Int. Conf. Manage. Innov. Technol.*, 2016, pp. 25–30.
- [49] "MIA Spotlight: Shedding Light on Ajaita Shah," Yunus Social Bus., 2019. Accessed: Apr. 10, 2020. [Online]. Available: <https://www.yunusfb.com/blog/2019/2/26/shedding-light-on-ajaita-shah-an-entrepreneur-of-the-man-impact-accelerator>
- [50] H. Nari Kahle, A. Dubiel, H. Ernst, and J. Prabhu, "The democratizing effects of frugal innovation: Implications for inclusive growth and state-building," *J. Indian Bus. Res.*, vol. 5, pp. 220–234, 2013.
- [51] Nuru Energy, "Join us in our mission to bring clean energy to every village in the world," *Nuruenergy.org*, 2020. Accessed: Apr. 10, 2020. [Online]. Available: <http://www.nuruenergy.org/>
- [52] Nuru Energy, "Business Call to Action," 2020. Accessed: Apr. 10, 2020. [Online]. Available: <https://www.businesscalltoaction.org/member/nuru-energy>
- [53] Parmigiani and M. Rivera-Santos, "Sourcing for the base of the pyramid: Constructing supply-chains to address voids in subsistence markets," *J. Oper. Manage.*, vol. 33/34, no. 1, pp. 60–70, 2014.
- [54] Frontier Markets, 2020. Accessed: Apr. 12, 2020. [Online]. Available: <https://frontiermkts.com/partners/>
- [55] Clean Cooking Alliance, "Partner Spotlight: WANA Energy Solutions," 2017. Accessed: Apr. 11, 2020. [Online]. Available: <https://www.cleancookingalliance.org/about/news/08-25-2017-partner-spotlight-wana-energy-solutions.html>
- [56] A. Pisoni, L. Michelini, and G. Martignoni, "Frugal approach to innovation: State of the art and future perspectives," *J. Cleaner Prod.*, vol. 171, pp. 107–126, 2018.
- [57] J. Prabhu, "Frugal innovation: Doing more with less for more," *Philos. Trans. Roy. Soc. A—Math. Phys. Eng. Sci.*, vol. 375, 2017, Art. no. 20160372.
- [58] C. K. Prahalad and A. Hammond, "Serving the world's poor, profitably," *Harvard Bus. Rev.*, 2002. Accessed: May 17, 2019. [Online]. Available: <https://hbr.org/2002/09/serving-the-worlds-poor-profitably>
- [59] S. Ray and P. K. Ray, "Product innovation for the people's car in an emerging economy," *Technovation*, vol. 31, no. 5/6, pp. 216–227, 2011.
- [60] B. C. Rao, "Advances in science and technology through frugality," *IEEE Eng. Manage. Rev.*, vol. 45, no. 1, pp. 32–38, Jan.–Mar. 2017.
- [61] B. C. Rao, "Science is indispensable to frugal innovations," *Technol. Innov. Manage. Rev.*, vol. 8, pp. 49–56, 2018.
- [62] J. S. Rego and A. A. Corradi, "ICH and 'frugal innovation': A contribution to development through the framework of the 2003 Cogvention," *Int. J. Intangible Heritage*, vol. 13, pp. 174–188, 2018.
- [63] R. Reinhardt, S. Gurtner, and A. Griffin, "Towards an adaptive framework of low-end innovation capability—A systematic review and multiple case study analysis," *Long Range Planning*, vol. 51, pp. 770–796, 2018.
- [64] SEED, "RECFAM—Pride Pads," 2017. Accessed: Apr. 16, 2020. [Online]. Available: <https://seed.uno/enterprise-profiles/recfam-pride-pads>
- [65] E. Rosca, G. Mollering, A. Rijal, and J. Bendul, "Supply chain inclusion in base of the pyramid markets: A cluster analysis and implications for global supply chains," *Int. J. Phys. Distrib. Logistics Manage.*, vol. 49, pp. 575–598, 2019. [Online]. Available: <https://doi.org/10.1108/IJPDLM-01-2018-0042>
- [66] E. Rosca, M. Arnold, and J. C. Bendul, "Business models for sustainable innovation - an empirical analysis of frugal products and services," *J. Cleaner Prod.*, vol. 162, pp. S133–S145, 2017.
- [67] E. Rosca, J. Reedy, and J. C. Bendul, "Does frugal innovation enable sustainable development? A systematic literature review," *Eur. J. Develop. Res.*, vol. 30, pp. 136–157, 2018.
- [68] Safi Organics and Ashoka, "Everyone a changemaker," Ashoka, Bengaluru, India, 2020. Accessed: Apr. 10, 2020. [Online]. Available: <https://www.ashoka.org/de/story/safi-organics>
- [69] Safi Organics, "Decentralizing Fertilizer Production," *Safiorganics.co.ke*, 2020. Accessed: Apr. 12, 2020. [Online]. Available: <http://safiorganics.co.ke/>
- [70] "Sameer Hajee (MBA '04D) of Nuru Lighting company on creating affordable lighting in Africa," INSEAD, Fontainebleau, France, 2012. Accessed: Apr. 3, 2020. [Online]. Available: <https://www.youtube.com/watch?v=tE7grgR5p1k>
- [71] V. Sehgal, K. Dehoff, and G. Panneer, "The importance of frugal engineering—Strategy+business," 2010. Accessed: Jul. 2, 2020. [Online]. Available: <https://www.strategy-business.com/article/10201?gko=56907#:~:text=Cost%20discipline%20is%20an%20intrinsic,markets%20is%20a%20losing%20game>
- [72] R. Shah and P. Ward, "Lean manufacturing: Context, practice bundles, and performance," *J. Oper. Manage.*, vol. 21, no. 2, pp. 129–149, 2003.
- [73] R. Sharmelly and P. K. Ray, "The role of frugal innovation and collaborative ecosystems: The case of Hyundai in India," *J. General Manage.*, vol. 43, pp. 157–174, 2018.
- [74] K. T. Shibin, R. Dubey, A. Gunasekaran, Z. W. Luo, T. Papadopoulos, and D. Roubaud, "Frugal innovation for supply-chain sustainability in SMEs: Multi-method research design," *Prod. Planning Control*, vol. 29, pp. 908–927, 2018.
- [75] E. Simanis, "Reality check at the bottom of the pyramid," *Harvard Bus. Rev.*, 2012. Accessed: Jun. 23, 2019. [Online]. Available: <https://hbr.org/2012/06/reality-check-at-the-bottom-of-the-pyramid>
- [76] Solarimpulse. Accessed: Apr. 10, 2020. [Online]. Available: [https://solarimpulse.com/companies\\_file/ekasi.energy-1.pdf](https://solarimpulse.com/companies_file/ekasi.energy-1.pdf)
- [77] P. Soni and R. T. Krishnan, "Frugal innovation: Aligning theory, practice, and public policy," *J. Indian Bus. Res.*, vol. 6, pp. 29–47, 2014.
- [78] United Nations Climate Change, "The Bamboo Bikes | Ghana." Accessed: Apr. 12, 2020. [Online]. Available: <https://unfccc.int/climate-action/momentum-for-change/women-for-results/ghana-bamboo-bikes-initiative>
- [79] R. Tiwari and C. Herstatt, "Assessing India's lead market potential for cost-effective innovations," *J. Indian Bus. Res.*, vol. 4, pp. 97–115, 2012.
- [80] R. Tiwari and C. Herstatt, "Frugal innovation: A global networks' perspective," *Die Unternehmung*, vol. 66, no. 3, pp. 245–274, 2012.
- [81] R. Tiwari and K. Kalogerakis, "Innovation pathways and trajectories in India's auto component industry," *Inst. Technol. Innov. Manage.*, Hamburg Univ. Technol., Hamburg, Germany, Working Papers 98, 2017.
- [82] M. V. S. Valiathan, "Frugal innovation in cardiac surgery," *Indian J. Thoracic Cardiovascular Surg.*, vol. 34, pp. 439–448, 2018.
- [83] C. Van Beers, P. Knorringer and A. Leliveld, "Frugal innovation in Africa: Tracking Unilever's washing-powder sachets," *Transforming Innovations in Africa: Explorative Studies on Appropriation in African Societies*, vol. 11, Leiden, Netherlands: BRILL, 2012, pp. 59–77.
- [84] S. Verma, "Frugal innovation in medical devices: Key to growth in emerging economies," *J. Med. Marketing*, vol. 16, pp. 66–73, 2017.
- [85] S. K. Von Janda, M. Schuhmacher, and G. Shainesh, "What frugal products are and why they matter: A cross-national multi-method study," *J. Cleaner Prod.*, vol. 246, 2020, Art. no. 118977.
- [86] WANA Energy Solutions, "WANA Energy Solutions—Affordable Cooking Solutions—Cook With a Smile," 2020. Accessed: Apr. 10, 2020. [Online]. Available: <http://wesgas.co.ug/>
- [87] Wana Energy Solutions, Miller Center for Social Entrepreneurship, 2014. Accessed: Apr. 10, 2020. [Online]. Available: [https://www.youtube.com/watch?v=DZm\\_IdIPzwo](https://www.youtube.com/watch?v=DZm_IdIPzwo)
- [88] PridePad, "What we've achieved—Pridepad Ghana," 2020. Accessed: Apr. 10, 2020. [Online]. Available: <https://pridepadghana.org/what-weve-achieved/>
- [89] S. Winterhalter, M. B. Zeschky, L. Neumann, and O. Gassmann, "Business models for frugal innovation in emerging markets: The case of the medical device and laboratory equipment industry," *Technovation*, vol. 66/67, pp. 3–13, 2017.
- [90] J. P. Womack and D. T. Jones, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. London, U.K.: Touchstone Books, 1998.
- [91] T. Weyrauch and C. Herstatt, "What is frugal innovation? Three defining criteria," *J. Frugal Innov.*, vol. 2, 2016, Art. no. 1.
- [92] Q. Zhu, J. Sarkis and K. Lai, "Confirmation of a measurement model for green supply-chain management practices implementation," *Int. J. Prod. Econ.*, vol. 111, no. 2, pp. 261–273, 2008.
- [93] M. Zomorodi, S. Fayezi, K. H. Lau, and A. McMurray, "Supply-chain adaptations for the base-of-the-pyramid business: Towards a theoretical model," *Int. J. Phys. Distrib. Logistics Manage.*, vol. 49, no. 5, pp. 599–624, 2019.
- [94] N. Radjor and J. Prabhu, *Frugal Innovation: How to Do More with Less*, U.K.: Profiles Books Ltd, 2015.
- [95] Y. A. Bhatti, "What is frugal, What is innovation? towards a theory of frugal innovation," Feb. 1, 2012. [Online]. Available: <https://ssrn.com/abstract=2005910>



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