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Doing more with less - How frugal innovations can contribute to improving healthcare systems

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ABSTRACT

The dominance of an innovation discourse laden with cutting edge and expensive technologies, may be preventing us from recognizing alternative and complementary perspectives, which could help cut healthcare costs while improving worldwide access to health services. One such complementary approach is that of frugal innovation. Frugal innovation, as a way to produce efficacious and affordable products using fewer resources to reach the underserved customers, has received increasing attention in the social sciences literature. Although frugal innovation is commonly associated with emerging economies, there is now a rising interest from healthcare providers in developed countries, to find and apply effective, and lower-cost solutions. Nonetheless, knowledge on frugal innovation and its role in healthcare is dispersed across different literatures which hampers researchers and practitioners to access a fuller, and integrated picture of the phenomenon. In this study, by synthesizing extant knowledge, we tackle the fragmentation of the phenomenon. We elucidate on who the actors are, what is being done, how are such innovations being developed, and what the outcomes are, providing a framework that lays out the underlying mechanisms of frugal innovation in healthcare (FIH). The midrange theory that we develop, provides a conceptual framework for researchers to undertake empirical observation and models to guide managerial practices. Furthermore, by providing a more unified perspective of frugal innovation in healthcare, we hope to initiate conversations on the development, adequacy and adoption of these innovations in healthcare services, which could increase affordability and access for the population while maintaining quality.

1. Introduction

Healthcare systems and technologies have evolved tremendously over the last decades, with marked improvements in healthcare delivery, and successful containment of many diseases. The development of vaccines and pharmaceuticals which have enabled the conquest of once-devastating illnesses such as smallpox and polio, and the better understanding of underlying mechanisms causing many diseases, has led to a marked improvement in our ability to prevent, diagnose, and treat common afflictions such as diabetes and heart diseases (Institute of Medicine, 2008). These, and other advances, have contributed towards the increase of the average global life expectancy at birth, by 5.5 years between 2000 and 2016, and the reduction in mortality of children under the age of five in low-income countries by 53 per cent (WHO, 2020a). Yet, critical problems remain. Only about one-third to one-half of the global population is covered by essential health services, and if this trend continues, these numbers are expected to remain between 39 and 63 per cent in 2030, and even lower in poor countries (United Nations, 2020). Resource constraints in healthcare systems in low and middle-income countries (LMICs) (Prime et al., 2017; Dessap, 2019), and financial barriers to care (such as user fees) for both public and private systems imply its limited access to the citizens of these countries, especially in rural areas (Basu et al., 2012; Gu et al., 2009 and references therein). High-income countries (HICs) also face multiple challenges due to slower economic growth, high healthcare systems costs, and an increasingly aging society (Halfmann et al., 2019; Prime et al., 2017). The COVID-19 pandemic has put further strains on healthcare systems globally, reinforcing urgent calls to find new and less expensive healthcare solutions (Sarkar, 2021; United Nations, 2020).

Historically, medical innovations have been important drivers in the improvement of healthcare systems. Yet these innovations, such as sophisticated and complex medical devices, albeit not the sole responsible,

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have also contributed towards augmented costs in healthcare services. For instance, a magnetic resonance imaging (MRI) unit may cost from 2 to 8 million dollars which is likely to strain the health budgets in LMICs where even more standard equipment such as an anesthesia machine (US$ 5000) may be difficult to acquire (WHO, 2010, and references therein). As medical devices are often developed for resource-endowed social contexts of HICs, they are frequently not affordable, useful, or appropriate to be used in resource-constrained settings, thus intensifying health disparities between different countries, as well as between social groups (Dessap, 2019; Lehoux et al., 2016, and references therein; Valiathan, 2018). Confronted with these and other inefficiencies, healthcare leaders have been working globally on improving the quality of their services while reducing costs and promoting inclusivity (Bianchi et al., 2017; Prime et al., 2017). The dominance of an innovation discourse laden with research and development (R&D) investments, and cutting edge and expensive technologies, may be preventing us from recognizing alternative and complementary perspectives to achieve effective healthcare solutions. Although innovation trends have been moving from being science-led fueled by technological advances, to also include a more a practice-based innovation approach powered by "resources at hand" (Farchi and Salge, 2017; Essén and Lindblad, 2013), inclusivity remains a problem to be tackled. One complementary way, which could contribute towards providing effective, affordable and inclusive solutions in healthcare systems, is through frugal innovation (FI).

When actors are faced with resource constraints, they can trigger cost-effective, and good-enough quality solutions (Gibbert et al., 2014; Lim and Fujimoto, 2019). Innovations emerging from resource constrained contexts, are deemed as being "frugal", often involving adaptations and reengineering of pre-existing technologies (Sarkar and Pansera, 2017). While the definition of FI depends on the perspective (Bhatti et al., 2017), it has generally been understood to be "low-cost and efficacious, new or adapted products (or services), mostly emerging from contexts of institutional voids and resource constraints, involving the creative use of existing resources" (Sarkar, 2021, p.2). FI is based on strategies of "doing more with less for more" (Prabhu, 2017, p.1), creating value by using less resources and for more people. While technological advances and innovations have been mostly associated with HICs, there has been an increasing number of LMICs, especially in Asia, which have been transitioning towards innovation-driven economies (Liu et al., 2019). LMICs are becoming not only important as consumers, but also as producers, shifting the gravitational center of global economic activity (Ghauri et al., 2021). Innovations emerging from these contexts tend to be less resource-intensive, more robust, as well as more affordable (Tiwari and Herstatt, 2012). Although the FI phenomenon has been mainly associated with LMICs, FIs with "characteristics of reframing constraints, bridging access, and enacting new business models" (Lim and Fujimoto, 2019, p.1017), are now recognized to be also important for HICs (European Commission, 2016; Lim and Fujimoto, 2019). Furthermore, some of these innovations "adopted first in poor (emerging) economies before 'trickling up' to rich countries" (Govindarajan and Ramamurti, 2011, p.191) represent a flow of innovation transferred from LMICs to HICs, referred to as reverse innovation (RI). An example of RI in healthcare is the General Electric (GE) ultrasound machine, first marketed in China but which was later found to be efficient enough to be marketed in HICs such as the USA, where it is used, for instance, in emergency units and ambulances. (Hossain et al., 2016; Zeschky et al., 2011). More recently, the development of FI has shown to be an important contributor in the tackling of the COVID-19 pandemic (Harris et al., 2020; Sarkar, 2021), further stimulating interest on FI by scholars and practitioners.

As the idea of innovations arising out of resource-poor contexts is based on a different paradigm compared to the R&D driven innovation discourse today, it attracts scholarly interest (Hang et al., 2010; Prahalad, 2012; Sarkar and Pansera, 2017). Researchers have also started to examine healthcare innovations emerging from such contexts. FI in healthcare (FIH) from LMICs, which potentially combine cost and resource appropriateness concerns, yet geared towards performance or effectiveness, promise a cheaper, alternative, and complementary strategy for many countries. For instance, the development of FIH products by hospitals and physicians in LMICs which often struggle to acquire standard equipment, has been studied by some authors (Bianchi et al., 2017; Hossain, 2017). In the COVID-19 pandemic context, Sarkar (2021) highlights some innovations that are low-cost, but still provided effective and complementary defensive aids in the fight against the pandemic in the Indian state of Kerala. Corsini et al. (2020) also presented the example of the rapid development of face-shields in the Maker's Asylum in Mumbai.

Being an emerging research field, researchers are only now beginning to enquire into FIH. Notable scholarly efforts have recently contributed with qualitative studies. However, these studies are dispersed across different literature fields, and in particular in medicine and management (see Appendix A). As the two research fields often remain distinct, our understanding of the phenomenon thus remain fragmented. Moreover, qualitative studies often do not provide enough basis for generalizations (Eisenhardt, 1989). Therefore, by remaining isolated, the opportunity to inform researchers and practiotioners through knowledge accumulation and robust generalizations is hampered (Habersang et al., 2019). Hence, for this emerging research area to sink stronger roots, there is much to gain from a more integrated understanding of FIH. Such appreciation should ideally synthesize the main empirical contributions from both research streams, and also elucidate on who the actors are, what is being done, how are such innovations being developed, as well as identifying the outcomes. In this paper, we seek to provide a foundation for future studies to examine FIH. Towards this, we synthesize extant knowledge (Jaakkola, 2020), focusing on empirical cases to discuss the phenomenon's distinctive features, explicating higher-order constructs by subsuming the phenomenon's complexity (Cornelissen, 2017), to reveal the mechanisms by which FIH unfolds. We provide a framework unifying the higher order dimensions we have considered: the actors ("who"), motivations ("why"), process ("how") and outcomes ("what"), to provide a more complete and enhanced analysis of the phenomenon (Buckley and Prashantham, 2016; Page and Vella-Brodrick, 2009; Prilleltensky, 2012; Secundo et al., 2021). We adopt a narrative idiom to explain FIH around a generalized process mechanism, as the underlying storyline (Langley, 1999). The midrange theory that we therefore develop, provides a conceptual guide for the development of new theoretical perspectives, and for researchers to undertake empirical observation and models to guide managerial practices (Jaakkola, 2020).

We begin our narrative by situating the current background on the concept of FI (section 2). In section 3, we present and describe our framework regarding the phenomenon's antecedents, process, and outcomes. In section 4, we discuss the study's main contributions for research, practice and society. Finally, in section 5, the main limitations of this study are outlined along with suggestions on future research directions.

2. Conceptual background of frugal innovation

The frugal innovation concept has its roots in the "appropriate technology" movement (Kaplinsky, 2011; Schumacher, 1973) which called for the employment of "technologies which are appropriate for low-income countries in that they are labour-intensive, simple to operate and repair, producing products for low-income consumers" (Kaplinsky, 2011, p.195). The relevance of the potential to innovate using few resources, follows the recognition by scholars that the innovation potential may be even bigger in LMICs, where markets are bigger and less saturated, and where "surprising ways of using current innovation or out-dated technologies in new ways can be found" (Sarkar and Pansera, 2017, p.328). This suggests that especially in a resource constrained world, there exists an enormous potential for innovations to be

of a low-cost and "frugal" nature (Sarkar and Pansera, 2017). Over the last decade, the FI concept has gained increasing popularity amongst practitioners and innovation scholars alike. Wooldridge, writing in The Economist (2010), noted that when it comes to FI, "There is more to this than simply cutting costs to the bone (…). Frugal innovation is not just about redesigning products; it involves rethinking entire production processes and business models" (pp.3–4). While efforts have been carried out in the search for a consensual definition (Bhatti and Ventresca, 2012; Hossain, 2018; Pisoni et al., 2018; Weyrauch and Herstatt, 2016), there is a broad understanding that FI aims at serving the needs of the underserved populations by providing robust, low-cost but efficient solutions. With initial research trends tending to focus on FI in the resource constrained environments of LMICs, it is now emerging as a more global phenomenon, and increasingly finding relevance in HICs (Bhatti et al., 2017; Kroll and Gabriel, 2020; Pisoni et al., 2018 and references therein). Extant innovation discourse tends to follow a Silicon Valley bias, with a focus on creation of new technologies fueled by R&D, and has been criticized for its "western techno-fetishism of novelty" (Keane and Zhao, 2012, p.223). FI therefore provides an alternative and complementary dimension to this dominant narrative, one that emerges from resource-poor economies. As the discussion around FI moves from LMIC to HIC settings (e.g., European Commission, 2017; Lim and Fujimoto, 2019; Weyrauch and Herstatt, 2016), this phenomenon makes a case for what richer countries can learn from the poor.

Current FI management research goes beyond innovation studies, embracing areas such as entrepreneurship (Hossain and Sarkar, 2021), sustainability (Khan, 2016; Pansera and Sarkar, 2016; Rosca et al., 2017; Tesfaye and Fougère, 2021), and more recently in healthcare (Bianchi et al., 2017; Corsini et al., 2020; Winterhalter et al., 2017; Sarkar, 2021). Furthermore, there is an increased recognition that being frugal does not necessarily mean creating products which sacrifice on performance levels (Sarkar, 2021; Weyrauch and Herstatt, 2016). For instance, Weyrauch and Herstatt (2016) consider that FI not only shares the two more generally recognized frugal attributes of substantial cost reduction, and concentration on core functionalities, but can also imply optimized performance level. This recognition of "optimal performance" has shifted the debate of FI not only being centered on low price, but that FI can also imply high quality, ease of use, and robustness (Lim and Fujimoto, 2019; Rao, 2013; Sarkar, 2021; Zeschky et al., 2011; Weyrauch, 2018). We argue that this re-examination of FI as geared towards performance or effectiveness, is therefore also very relevant when it comes to FIH, which potentially combine cost and resource appropriateness concerns, with function analysis which "focuses on what functions must be included in an object in order to fulfil the requirements placed on the object" (VDI, 2019, p. 3, as cited in Winkler et al., 2020).

3. Frugal innovation in healthcare (FIH)

Our explanation of the phenomenon follows a qualitative evidence synthesis often used to synthesize complex interventions, and ideal for studying processes (Combs et al., 2019; Rauch et al., 2014). Using qualitative means, we are able to better appreciate the richness of the FIH phenomena, by considering their relational and temporal contexts (Garud et al., 2018). The qualitative evidence we synthesize was extracted from empirical data or case studies in extant literature, published in both medicine related and management journals. From this analysis, we arrive at FIH's higher-order constructs that help us to subsume the phenomenon's complexity (Furnari et al., 2020), provisioning its more complete and enhanced analysis (Buckley and Prashantham, 2016; Page and Vella-Brodrick, 2009; Prilleltensky, 2012; Secundo et al., 2021). We organize our explanation using a narrative methodology (Elliot, 2005) that informs the progression of ideas around four broad themes of FIH incidence: actors (*who*?) embedded in a description of what is FIH; the antecedents (*why*?); process (*how*?); outcomes (*what*?).

Before delving into the narrative which synthesizes and integrates the qualitative and empirical data found, we present the conceptual framework that distil the progression of ideas of the antecedents, processes, and outcomes of FI in healthcare (Fig. 1). These are connected as a process, which has a combinatorial logic that enables us to understand how the "different elements of the configuration relate to one another to produce the outcome in an analytical way" (Park et al., 2020, p.9). In the next subsection, we initiate the narrative by defining and describing FIH. We then characterize FIH along the four themes defined, complementing the narrative with some real case examples.

3.1. What is FIH?

We define FIH as a resource parsimonious innovation process, to produce appropriate and efficacious healthcare related goods or services, at low costs and implicating the creative use of existing resources. FIH not only harbours the promise of low-cost innovations, but it also involves more open platforms with the participation and collaboration of varied actors as we shall defend. FIH as a research field is still incipient, with scholars recently contributing with qualitative studies, frequently in medical (and related) journals (e.g. Bhatti et al., 2017; O'Hara, 2015; Valiathan, 2018).[1] To aggregate information on what FIH may mean, Arshad et al. (2018) reviewed extant literature to identify patterns of FI in healthcare regarding the type of innovators and innovations, the country of origin and first launch market, type of care, and geographical diffusion. These authors were then able to provide an overview of these characteristics mainly relying on percentage analysis. Another effort at aggregating evidence was that of Tran and Ravaud (2016), who classified FIH according to the technological complexity of the devices and the developers' context in a reverse relationship, implying that solutions based on simpler technologies are "homegrown" with more complex technologies involved when developed in richer contexts. These authors suggest the following four subtypes of FIH (ranging from lower to higher technological complexity) - Bottom-up innovations, contextualized adaptations, opportunistic solutions, and lean tool and techniques. While these attempts at aggregating evidence provide a summary outlook on the characteristics of FIH, we remain ignorant on the phenomenon's mechanisms explaining events and outcomes. Our study takes a further step in opening the area for future studies, by providing a conceptual background and then extracting key higher order dimensions of the concept, to produce an integrative view of the phenomenon.

FIH encompasses a wide range of solutions, which are consistently low-cost, and of an adequate performance level to serve the underserved populations. While authors consider that FI can comprise of products, services, processes, or business models (Hossain et al., 2016; Prabhu, 2017), most FI studies have however concentrated on products. Our FIH analysis is similarly focused on frugal products as a boundary condition, for two reasons. First, the development and implementation of healthcare products are different from the other types of innovations, which makes it difficult to explore each one in detail in the same body of work. Second, it gives us an opportunity to aggregate and conceptually discuss an emerging yet fragmented literature, and by using a homogenous group it enables us to gather more valid and relevant research findings (Lee et al., 2013).

3.2. FIH innovation types and the actors

Frugal products in healthcare include preventive tools, diagnostic and monitoring tools, surgical tools, and therapeutic or rehabilitative devices. Fig. 2 presents a set of examples of each one. In FIH, maintaining a certain level of quality and efficiency is a top priority, with the

[1] In Appendix A, we present examples of studies containing information on cases of FIH, which have contributed towards constructing our integrative view of the phenomenon.

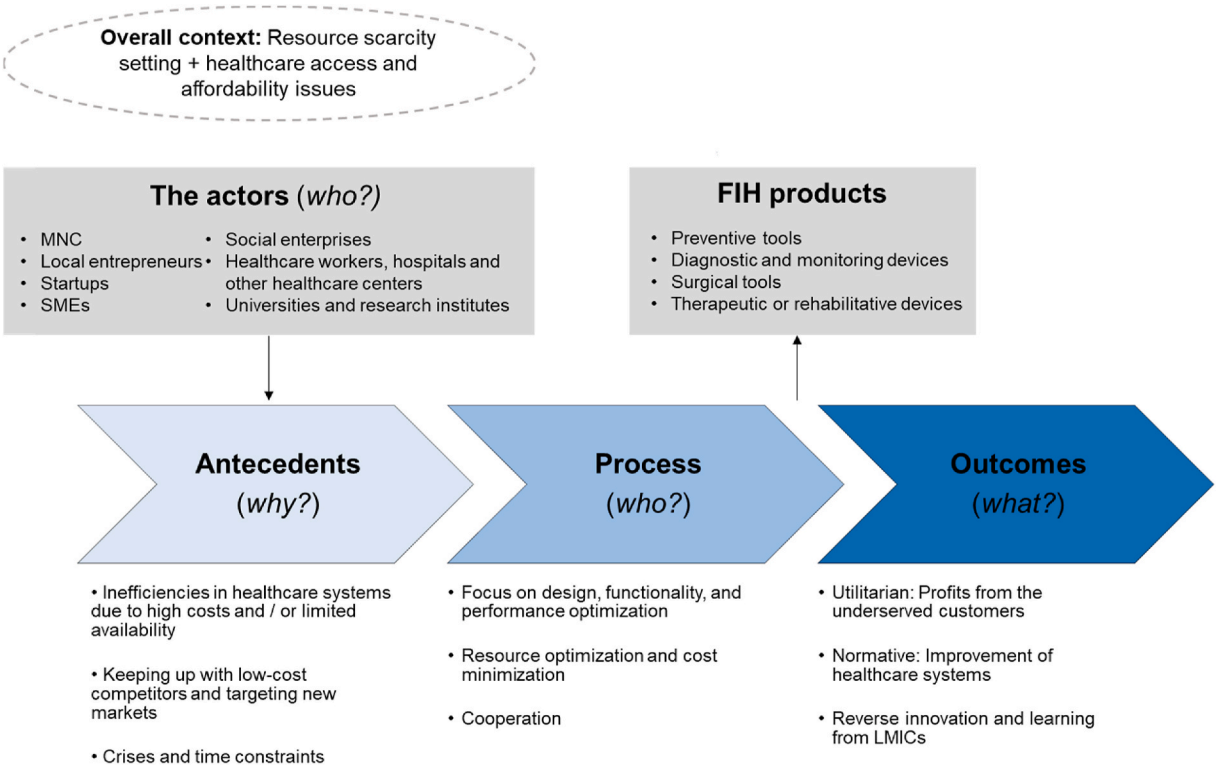

Fig. 1. FIH conceptualization regarding the actors, antecedents, process, and outcomes.

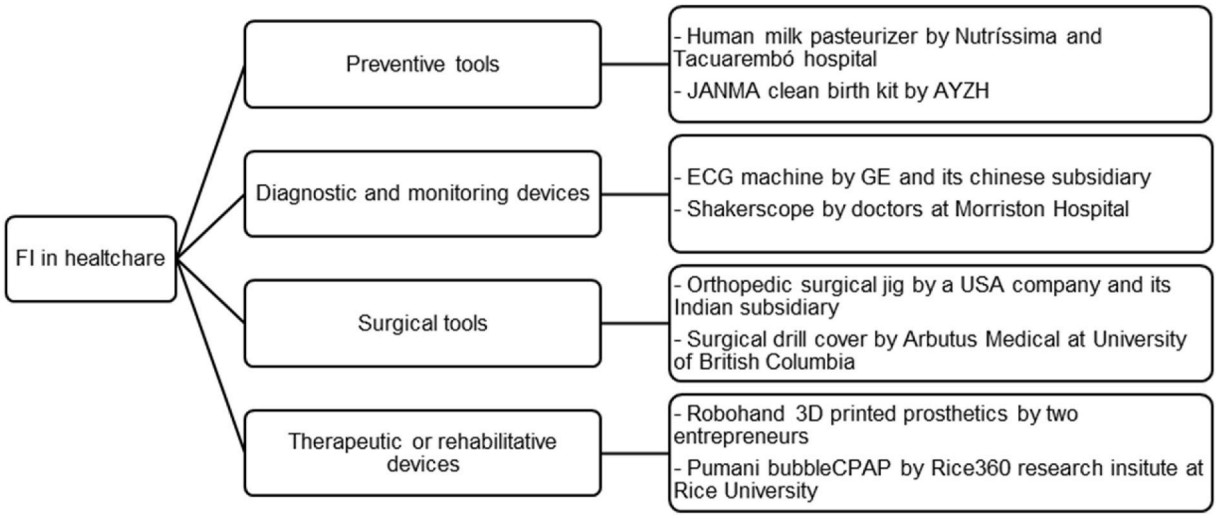

Fig. 2. FIH - Types and some examples.

objective "to provide safe healthcare in the best way possible under given circumstances and constraints" (Harris et al., 2020, p.814).

A diverse range of actors from both HICs and LMICs can be involved in the development of FIH, including multinational companies (MNCs), local entrepreneurs, startups, small and medium-sized enterprises (SMEs), social enterprises, healthcare workers, hospitals and other healthcare centers, universities, and research institutes. In this section, we elaborate on a few examples to illustrate the diversity of actors developing FIH. We then summarize (Table 1) a broader set of examples of FIH and its actors. These and other examples are further explored regarding the associated motivations, processes, and outcomes in the subsequent sections of this paper.

Some MNCs from HICs have been engaging in FI for healthcare for some time. For instance, GE has produced a frugal ultrasound machine, an electrocardiogram (ECG) device, and a baby warmer, while Siemens developed a frugal computerized tomography (CT) scanner, and a fetal heart rate monitor. These devices are not only cheaper than their standard equivalents but were developed taking into consideration the rough conditions of use in the target market (LMICs) being adjusted to be used in those settings (Agarwal and Brem, 2012; Hossain, 2017; Zeschky et al., 2011). While most of the examples found, begin by targeting LMICs, some have shown to be good-enough to later penetrate HICs markets (RI) (Agarwal and Brem, 2012; Zeschky et al., 2011). For instance, Siemens's X-ray machine MultiSelect DR costs around 30 per c less than their equivalent high-end products, and still has sufficient quality to comply with most standards in HICs. Therefore, it is not only

Table 1
Examples of FIH products and actors involved.

FIH product	Type of innovation	Actors' country	Type of agent
ECG machine and ultrasound machine by GE	Diagnostic and monitoring	USA	MNC
CT scanner, fetal heart rate monitor and R-ray machine by Siemens	Diagnostic and monitoring	Germany	MNC
Bedside monitoring system by Phillips	Monitoring	Netherlands	MNC
iBreastExam device to detect breast cancer by UE LifeSciences	Diagnostic	India + USA	MNC
Face shield by Maker's Asylum co-founders	Preventive	India	Local entrepreneurs
Robohand 3D printed prosthetics by Richard Van As and Ivan Owen	Rehabilitative	South Africa + USA	Local entrepreneurs
Valves for ventilator by Isinnova	Therapeutic	Italy	Startup
Human milk pasteurizer by Tacuarembó hospital and Nutríssima	Preventive	Uruguay	Hospital + SME
PEEK portable eye examination kit by Peek Vision	Diagnostic	UK	Social enterprise
Baby incubator by Embrace	Preventive	USA	Social enterprise
TTK-Chitra heart valve by Sree Chitra Tirunal Medical Center	Surgical	India	Healthcare center
Shakerscope by doctors at Morriston Hospital	Diagnostic and monitoring	UK	Healthcare worker entrepreneur
Jaiupur Foot prosthetic limbs by Dr. P.K. Sethi	Rehabilitative	India	Healthcare worker entrepreneur
Pumani bubbleCPAP respiratory device by Rice360 research institute at Rice University	Therapeutic	USA	University/ Research institute
Surgical drill cover by Arbutus Medical at University of British Columbia	Surgical	Canada	University/ Research institute

marketed in LMICs but also used in HICs mainly as backup equipment (Agarwal and Brem, 2012).

FI in healthcare can arise from the local needs, provoking user-actors to craft innovative solutions. The Jaipur Foot is a low-cost prosthetic limb created by the Indian doctor P.K. Sethi, for barefoot amputees. The product is manufactured by local artisans using readily available materials (Grover et al., 2014). This is an example where physicians, who understand real needs and conditions in healthcare of the local population, become active actors in FIH. Sethi observed that amputees would rather use crutches than prostheses fitted with a Solid Ankle Cushion Heel foot (SACH), as these were unsuitable for "floor-sitting" lifestyle in the hot and humid conditions of India (Arya and Klenerman, 2008). Another example of FIH developed by physicians is the ShakerScope, a light source for eye, ear and throat examination which produces power by shaking and was developed by two anesthesiologists from Morriston Hospital in Swansea, United Kingdom. The doctors were inspired to create a device which does not require electricity or battery, as they observed first-hand in Zambia that most conventional devices did not work due to erratic electrical power, which is common in many LMICs (Mandal, 2014).

FIH can also be stimulated by governments and hospitals policies. This is the case of an Uruguayan hospital, where in cooperation with local partners, a neuronavigation device and a human milk pasteurizer were developed. These innovation processes were enabled by using embedded local capacities to creatively use the available resources, aiming at surpassing technology access barriers to improve the desired service quality at lower costs (Bianchi et al., 2017). Universities and research institutes are another great source of FIH, and while they often lack support (Mandal, 2014), there are some successful cases such as the Pumani bubbleCPAP which is a low-cost respiratory support device designed by the research institute Rice360 at Rice University, USA (Tran and Ravaud, 2016; Prime et al., 2017). Moreover, since FIH "reduces the need for sophisticated labs and instead relies on clever brainstorming and a better grasp of basic engineering skills", students can be stimulated to pursue on innovation and entrepreneurship paths even in less well-equipped facilities (Mandal, 2014, p.12).

3.3. Motivations for FIH

We locate three key antecedents that motivate the development of FIH - healthcare system inefficiencies, keeping up with low-cost competitors and targeting new markets, and time constraints, each of which we now discuss below.

3.3.1. Inefficiencies in healthcare systems due to high costs and/or limited availability

The need for FIH is intrinsically connected to extant inefficiencies in healthcare systems worldwide. Due to spiraling healthcare costs, high-tech medical devices, and unavailability/inadequacy of these devices to be used in resource-constrained environments, quality healthcare services are not available for one third to one half of the global population (WHO, 2020a). Access to quality and appropriate healthcare is a major society concern, being imperative to find ways to provide universal access to quality healthcare services and tackle the existent disparities (Bianchi et al., 2017; Crisp, 2014; Lehoux et al., 2016; WHO, 2020a). This is one great motivator for FIH and in virtually all cases we have come across during our research, we find that there exists a desire to address this dimension of healthcare failure to some degree.

The trigger for the enaction of FIH may be identified by healthcare institutions and professionals themselves when faced with constraints such as lack of financial resources to acquire standard tools and equipment. These and other constraints cause limited availability of healthcare products which may stimulate users (for instance, healthcare professionals) to craft "demand induced innovations" (Bianchi et al., 2017, p.75). This has been happening since before the FI concept was even formulated, as was the case of the TTK-Chitra heart valve, which was conceived by a team of health professionals in the 1980s when it became impossible to import cardiac valves to meet the demands for the Chitra Medical Center, which offered free cardiac and neurological services to poor patients in India (Valiathan, 2018). The two must-have conditions of the cardiac valve for its developers, were affordability and compliance with ISO standards. After partnering with other institutions in India, and after a series of trial and error, the valve achieved those conditions and has been successful implanted in over 130,000 patients (Valiathan, 2018; TTK Healthcare, 2021). Similarly, in the search to provide universal access to quality health services, Tacuarembó Hospital in Uruguay has been able to use the available scarce resources to develop good quality frugal products. For instance, a team of hospital surgeons and engineers of a local university were able to develop a neuronavigation system which is simpler and more affordable than commercialized ones. Formerly, neuronavigation had not been yet used in the country due to its high cost (Bianchi et al., 2017). This therefore provided the means to enable local patients to access a technology which is available worldwide.

The desire to provide effective and low-cost solutions to improve the quality and availability of healthcare systems in LMICs, or other resource-constrained environments, can also come from actors in HICs, as we have previously seen in the case of the ShakerScope (Mandal, 2014). Another FIH product comes from a small company based at the

University of British Columbia in Canada, which developed a solution to tackle the unavailability of surgical drills in LMICs due to high costs. Since a surgical drill can cost around $30,000, surgeons often choose to use unsterile hardware drills to treat fractures, thus bearing a high risk of infection (Prime et al., 2017). The FIH solution is a drill cover system costing around $400 and composed of two sterilizable parts allowing for low-cost non-surgical drills to be used safely (O'Hara, 2015).

3.3.2. Keeping up with low-cost competitors and targeting new markets

Ventures may initiate FI processes to compete with low-cost products. For instance, GE developed an ultrasound machine for resource-constrained market segments after realizing that low-cost competitors from emerging economies were beginning to gain market share. Later, the company adapted its strategy to also commercialize its FI products in HICs (Zeschky et al., 2011). Similarly, with the objective to compete with local manufacturers and to gain market share in LMICs, Siemens created and engaged in a SMART initiative to develop frugal products which are "simple, maintainable, affordable, reliable and timely to market", some of them in the healthcare field. Examples of these include an X-ray machine and a fetal heart rate monitor (Agarwal and Brem, 2012). Philips is another company which engaged in FIH to offer a bedside patient monitoring system and replace the low-cost competitors in Chinese hospitals (Zeschky et al., 2011). To succeed in developing appropriate FIH for specific target markets such as LMICs, these MNCs often opt to deploy the development process and manufacture to local subsidiaries involving local teams which have or more easily gain the knowledge about the real conditions in which the product will be used, which is an essential step to assure adherence by the market (Winterhalter et al., 2017; Zeschky et al., 2011).

3.3.3. Crises and time constraints

Health crises such as the COVID-19 pandemic, may trigger FIH, when lack of time and resources emerge as critical constraints. The need to develop tools to monitor and manage the spread of diseases, aligned with the shortage of medical supplies and personal protection equipment was a global reality during the onset of COVID-19 pandemic. Citizens, ventures, and governments, both in LMICs and HICs, were forced to rapidly engage in ways to overcome this global problem, including FIH solutions (Corsini et al., 2020; Harris et al., 2020; Sarkar, 2021; Vesci et al., 2021). For instance, an Italian startup, Isinnova was able to rapidly develop valves for ventilators in collaboration with hospitals and a scuba dive masks manufacturer. Due to the magnitude of the pandemic, and the need to exponentially ramp up supply, the venture decided to make their patent design available so it could be manufactured elsewhere (Corsini et al., 2020; Vesci et al., 2021). The development of frugal diagnostic point-of-care-tests (performed in nonlaboratory settings) at a patient's bedside has become important during the pandemic as it allows reducing "extensive waiting times and unnecessary treatments and enable effective containment measures" (Miesler et al., 2020). Since crisis contexts obligate entrepreneurs to act fast to build and apply efficacious solutions, it represents an opportunity for HICs to gain knowledge and provide validation on the effectiveness of FI products, which is still mainly used in LMICs contexts. This could possibly and hopefully contribute to open up space for global knowledge and technology transfer (in the form, for instance, of RI – see outcomes' subsection), which could disrupt how innovation in healthcare occurs (Harris et al., 2020).

3.4. How? The process of FIH

We found the process development of FIH to rest on three main pillars – focusing on design and performance, resource optimization and cost minimization, and cooperation. We next discuss each of these.

3.4.1. Focus on design, functionality, and performance optimization

FIH goes beyond delivering low-cost and lower quality versions of Western products and services (Economist, 2010; Kuo, 2017; Zeschky et al., 2011). Instead, the solution "is refined to its maximum to answer precisely the need without concession on quality, but without superfluous addition" while aiming at affordability (Dessap, 2019, p.253). This is done by keeping in mind the contexts and constraints of the users. Constraints may be of diverse nature such as unreliable transport and electricity structures, lack of technically skilled workforce, issues on data connectivity and weak infrastructures (Mandal, 2014; Miesler et al., 2020). To develop products with adequate characteristics and performance, while maintaining low prices, developers of FIH pursue different strategies such as design simplification and maintaining focus on core functionalities. For instance, detection devices for infectious diseases in central laboratories and large hospitals are fully automated, operated under sterile environments and processing more than 300 samples in 6 to 8 hours. The case is different in rural scenarios, where it is more important for people to get quickly tested and treated and there are no infrastructural conditions or specialized people to operate these devices. Therefore, when a Dutch MNC decided to develop similar equipment for China and rural LMIC areas, they simplified the design allowing it to be used by less skilled personnel. It featured a single button and displayed the results in a very intuitive manner: green smileys for not infected, red smileys for infected (Winterhalter et al., 2017).

Simplifications for cost reduction can sometimes be achieved by substituting high-end technologies for simpler ones, such as in the case of Siemens' fetal heart rate monitor which incorporates simple microphones instead of expensive ultrasound technology, while also eliminating the cost of specialized personnel to operate the device (Kesavan and Dy, 2020). Nevertheless, simplification does not always imply that more recent technology was not used. The difference between FIH and conventional innovation in these cases, is that to keep costs low, functions are pared down to the essentials (Bianchi et al., 2017; Kuo, 2017). This means FIH can still feature high-end technologies, yet with fewer non-essential functions or simpler architectures, as in the case of the GE ultrasound machine or the Siemens CT scanner (Zeschky et al., 2011). FIH can moreover be the enabler for physicians and patients in resource-constrained settings to access high-end technology, such as the neuronavigation system developed in Tacuarembó Hospital in Uruguay (Bianchi et al., 2017).

There are other important features to be considered in the development of FIH, namely robustness and portability. Since many FI products are often designed to be used in rural areas, they must be transported through rough roads and used in less-than-ideal infrastructural conditions. These two features are often considered by developers of FIH, such as GE for their ultrasound device, or the Peek Vision for their portable eye examination kit (Zeschky et al., 2011; Prime et al., 2017) For example, being able to work under extreme weather conditions such as humidity and high temperature is an important feature for a FIH products (Winterhalter et al., 2017; Agarwal et al., 2021). Hence, when designing their detection devices for infectious diseases, which in standard conditions in HICs are operated under temperature-controlled environments, the Dutch MNC made sure it was able to work not only in a hot and humid temperature but also under temperature variations of the sample without compromising the result (Winterhalter et al., 2017).

Additionally, ease of use and maintenance are also important features to be incorporated in FIH products, as they are likely to be handled by less-experienced personnel in environments which are often too poor to perform maintenance of the equipment (Gupta and Thomke, 2018). Indeed, these are two of the most relevant characteristics noted by doctors, immediately after affordability, as observed by Agarwal et al. (2018) in their study on the differences and similarities of the top priorities for healthcare innovative products in India. UE LifeSciences, an USA-Indian venture realized, while developing a prescreening device for breast cancer (iBreastExam), that the ratio of radiologists in their target market (India) was extremely low – one radiologist per 100,000 people (in the USA there is one per 10,000). Therefore, the developers had to

focus on "low-resource providers" in local communities when designing the device to make in easy to use and decided that a one-button-design (on/off) without screens would be the most appropriate for the target user group, transferring the remaining functions to a mobile app (Agarwal et al., 2021). Lack of maintenance support in rural areas was similarly identified by GE as an important constraint during their development of the baby warmer. GE discovered that one important maintenance issue was the frequent replacement of the light bulb, which is critical for the machine's operation. To overcome this, they used LED lamps instead to increase longevity and reduce maintenance need, and while this increased the price of the product, the total cost of ownership was reduced (Agarwal et al., 2021).

3.4.2. Resource optimization and cost minimization

Resource optimization is an essential dynamic in FIH, given that the phenomenon mostly emerges from contexts that are resource-constrained, while also enabling to keep costs low. As resources in our context, we consider the following: financial, technology and materials, personnel, time, and infrastructure (Dessap, 2019). Actors focus on reducing costs along all stages: R&D, supply chain, manufacturing, and sales (Winterhalter et al., 2017). Savings in R&D by MNCs for instance, are often achieved by relying on local engineers and workers in the target market location (often LMICs). This strategy was used by GE regarding its frugal ultrasound machine. The product was developed in the company's Chinese subsidiary not only to take advantage of lower labor costs, but also to leverage the embedded knowledge possessed by the local team (Zeschky et al., 2011). One Dutch company, for instance, designed their frugal diagnostic tool mostly in their headquarters, and then outsourced its development to firms specialized in minimizing costs, since the team lacked low-cost developmental capabilities (Winterhalter et al., 2017).

Two other ways to optimize resources and performance, as well as reducing costs involve (1) using technologies which had been developed earlier and are then adjusted or repurposed (2) by decomposing multi-purpose machines into single operation devices (Winterhalter et al., 2017). Extant technologies and components can contribute towards the creation of medical low-cost products. These include 3D printing, miniaturization, artificial intelligence, cloud computing, lab-on-a-chip techniques, and components from mobile and microelectronics industry (Brem, 2017; Lundin and Dumont, 2017; Prime et al., 2017). For instance, PEEK, a portable eye examination kit, relies on a smartphone application and a lens adapter. PEEK enables capturing images which are of comparable quality of standard desktop retinal cameras, with the advantage of being portable and simple to use, two important features that make them useful in rural areas (Prime et al., 2017).

3.4.3. Cooperation

Another important dynamic in the FIH process is the collaborative aspect in its development. It is not enough to craft a new or adapted medical device, surgical tool, or other product innovations of adequate quality. Its acceptance by users is an important issue to keep in mind when developing such a product, whether in the case of FIH or for conventional innovations. In the case of FIH, product developers often have limited experience or medical knowledge. Therefore, they frequently seek to partner with healthcare facilities, such as hospitals, during the product's early development stages. This is the case of an Indian startup which sought to develop an affordable and non-invasive ophthalmological diagnostic device, however the team lacked experience and expertise in ophthalmology. They then partnered with an ophthalmology hospital, receiving feedback from doctors on the image quality of their prototypes through a series of trials, allowing continuous improvement of the product, which was successfully launched at the end of the first year of development (Gupta and Thomke, 2018). Conversely, when ideas merge from within healthcare systems, such as the ones devised by physicians or other medical staff, they often seek technological or manufacture partners to put their ideas into practice (Bianchi et al., 2017; Gupta and Thomke, 2018; Vesci et al., 2021). Gupta and Thomke (2018) observed however that physicians in LMICs such as India are more likely to partner with a new product developer than physicians in HICs, since regulatory and ethical guidelines and related penalties are much stricter in the latter. These authors argue that the development of FIH in LMICs tends to be much more interactive and less linear, featuring prototype testing in high-fidelity test environments along the process. This is important due to the lack of resources, experience, and infrastructure. Exceptions to this happened recently during the COVID-19 pandemic, where physicians, even from HICs were much more involved in the development processes of FI, due to the urgency and severity of the situation (Corsini et al., 2020). The role of cooperation in the development of frugal innovations has found rare mention in the literature, with some notable exceptions (Angot and Plé, 2015; Dahan et al., 2010; Sarkar, 2021; Sarkar and Mateus, 2022; Sharmelly and Ray, 2018).

Despite their superior resources, even MNCs find a need to collaborate. GE, for instance, partners with medical research institutes, state governments, and NGOs to provide affordable and accessible healthcare solutions in India and Bangladesh (Sarkar, 2021). Other types of cooperation including more strategic ones from the business viewpoint are also common when developing FIH. For instance, a Dutch MNC deployed a small team to develop a portable device for the detection of an infectious disease with the help of external partners. The production was carried out in Southeast Asia and the distribution and examination was then performed by NGOs in rural and resource-constrained areas (Winterhalter et al., 2017).

3.5. What: the outcomes of FIH

Three outcome dimensions typify FIH, broadly following a variant of the *triple bottom line approach*. Where the original concept implies the harmonic combination of economic, social and environmental goals (Cohen et al., 2008; Zahra et al., 2009), what we suggest is a combination of utilitarian (economic), normative (social), and an innovation related outcome of FIH. Below, we describe each of these.

3.5.1. Utilitarian - profits from the underserved customers

Although the motivations to create frugal products for healthcare almost always include the desire to contribute towards the improvement of global health and healthcare services, striving for financial sustainability and profits is an important goal for the majority of actors engaging in these innovation processes. Despite being able to create low-cost products, ventures can make good profit margins if the processes and business models behind the product are also low-cost (Winterhalter et al., 2017). Although this outcome is perceivable in the literature, there is not enough related information, extant information mostly restricted to MNCs. Although we have identified this outcome, we suggest future research to focus more on this topic, both to understand the profit differences in companies which operate by traditional and FI processes but also to gain knowledge about how a company solely based on FIH is able to economically thrive.

3.5.2. Normative - improvement of healthcare systems

As technology advances, healthcare systems have the potential to improve their efficacy. However, products and services based on new technologies tend to be available only for richer countries, as higher prices are generally applied to compensate the costs involved in the research and development stages. Eventually, competition and economies of scale kick-in, pushing prices down (Allen and Christie, 2016). These new technologies remain unavailable for a great proportion of the world's population, mostly in LMICs or the for the poorer in HICs. Therefore, FIH, by increasing affordability for both LMICs and HICs, can play an important role in increasing healthcare access worldwide.

By providing, for instance portable diagnostic tools and treatments which can be used in rural areas, FIH improves healthcare systems since

it allows to diagnose and treat people which otherwise would have remained undiagnosed and untreated due to the hardships involved in travel to rural areas. On the other hand, this also contributes towards reducing the number of patients in hospitals, allowing for health professionals to focus on the more severe cases which cannot be treated locally, again saving resources (Winterhalter et al., 2017). Some point-of-care diagnostic tools can even be used by patients themselves, further enhancing access (Lundin and Dumont, 2017).

3.5.3. Reverse innovation and learning from LMICs

A third outcome of the FIH phenomenon is the potential pivot from the learnings on innovation. Although a large majority of the development and investigation of FIH is focused on LMICs as the target market, RI, reflecting a backward flow, can be an important consequence and evolution of FIH. RI refers to cases "where an innovation is adopted first in poor (emerging) economies before "trickling up" to rich countries" (Govindarajan and Ramamurti, 2011, p.191). It has been noted that several FIH products have the potential of, and some are indeed already, being used in HICs, demonstrating that these countries can learn from LMICs regarding the good performance of products which do not have to be super expensive to work safely and effectively. Examples include the GE ultrasound machine which was first introduced in China and proved to be competent to be marketed in developed countries such as the USA, where it is used in emergency units and ambulances (Hossain et al., 2016; Zeschky et al., 2011). Other examples are some SMART frugal products by Siemens such as an X-Ray machine and a CT scanner which are used as in HICs, although more as backup devices (Agarwal and Brem, 2012). Some factors which may hinder RI include strict regulatory and insurance authorities, fear of monetary losses and product cannibalism by the manufacturers, difficulties in identifying competent innovations, and the bias against LMICs' innovations (Sharma and Cotton, 2021 and references therein; Zeschky et al., 2011). If HICs begin to consistently apply these mindsets and processes, FIH and RI can then ultimately contribute not only to decrease healthcare access inequalities between countries, but also within a country, by decreasing the costs of healthcare services.

4. Discussion

FIH with its minimal resource use to produce efficacious healthcare goods or services at low costs, can be an important complementary reinforcement in healthcare provision. With its promise of low-cost innovations, frequently in collaboration with other stakeholders, FIH solutions can provide affordable, and appropriate healthcare to the poorer citizens, whether in HICs or LMICs. While reducing spiraling healthcare costs in an increasingly aging society is a top priority in HICs, the challenge for LMICs is in providing affordable access to healthcare that is at the same time also appropriate for the resource-scarce settings (WHO, 2010). As a vast majority of the population in LMICs does not have access to quality healthcare (United Nations, 2020), and when medical equipment is available its performance is often not satisfactory, since LMICs contexts often lack the necessary infrastructure and resources for effective use and maintenance (O'Hara, 2015), FIH solutions can be a fitting remedy, even as a partial response strategy. FIH provides appropriate solutions for LMICs, by taking into consideration the local constraints, for instance, erratic power supply, during the development process (Sarkar and Pansera, 2017). Simply providing low-cost products developed in HICs is often not useful or appropriate in these contexts (Kuo, 2017). The recent COVID-19 pandemic mobilized a diverse range of actors to rapidly forge solutions which could help tackle the disease and its spread, both in LMICs and HICs (Corsini et al., 2020; Sarkar, 2021; Vesci et al., 2021). The urgency and stress placed on healthcare systems also represent an opportunity to rethink, in a context where current innovation processes and products in healthcare do not seem sustainable to provide services for everyone. FIH is worth studying as it has the potential to contribute to healthcare systems improvement in terms of affordability and, consequently, accessibility without compromising on adequate performance.

In our research we discuss the distinctive features of FIH, explicating higher-order constructs by subsuming the phenomenon's complexity (Cornelissen, 2017), to reveal the mechanisms by which FIH unfolds. By synthesizing knowledge from the emerging literature on FIH, derived both from medical related journals, as well as management, we pivot our understanding on the extant frugal innovation literature. Our study articulates a specific definition of FIH, locating this idea within the frugal innovation literature (e.g., Weyrauch and Herstatt, 2016; Sarkar, 2021), where parsimonious resource use, appropriateness, and affordability motivate cooperation and the creative use of existing resources. Our conceptualization encapsulates FIH as driven by the goals of inclusive and better social welfare, as well as utilitarian.

Fig. 1 conceptualizes how different actors' action and interaction lead to FIH. The resulting framework embedded within a resource scarcity setting, illustrates how this dynamic is motivated by the resolution of both utilitarian and normative concerns. As discussed earlier, a diverse range of actors can be involved in FIH, ranging from local doctors to MNCs, many times in cooperation to surpass resource constraints and develop products which contribute to the improvement of healthcare access, affordability, and quality.

The antecedents/motivations of actors engaging in FIH play out along three major dimensions. The first is the identification of the necessity and willingness to contribute towards providing accessible and appropriate healthcare services to resource-poor segments of the population. A second antecedent is with respect to firms' strategy to invest in resource-constrained markets, which although having low purchase power are of a very significant volume. As Prahalad and Hammond (2002), and then others (Tiwari and Herstatt, 2013) argued, there is a 'fortune' to be made from addressing the needs of the world's poorest, as high volumes can compensate thin margins. Therefore, the focus is on developing products which can be affordable for the target population while making sustainable margins and competing against local developers. Thirdly, a health crisis such as the COVID-19 pandemic is an almost automatic motivator to engage in FI for any type of actor. The time constraints and global effects posed by the disease stimulates people to quickly look out for FIH solutions.

The development of FIH comprises mainly of three strategies: optimizing design function and performance according to the target market, optimize the use of resources and cost minimization and finally, cooperation between entities. As we have seen, and in line with previous research on FI, simply providing low-cost versions of HICs products to LMICs or other resource-constrained settings, is not effective since most of these would not be able to be used due to weaknesses in infrastructure, lack of skilled personnel, high maintenance costs, among other challenges. Therefore, crafting solutions that adapt existing technologies, tailored to the users' needs and circumstances is essential. This implies that cost minimization along the development process must be achieved in order to be affordable. Since knowing the target market conditions is essential, cooperation with embedded and knowledgeable actors is often needed to fully potentiate the development and distribution of FIH products.

By putting the spotlight on the efficacy of resource-constrained innovations as a complementary approach to healthcare problems, we open both medical and management fields to a much richer discussion of the frugal innovation literature, one which holds that "more can be done with less". In this new conversation that we wish to promote in this field, our study implications on research, practice, as well as social, can further the dialogue on FI as an affordable yet efficacious healthcare response. We summarize next these implications.

4.1. Research implications

First, by providing an analysis of FIH in terms of the actors, antecedents, processes, and outcomes we provide a phenomenological

overview of the topic (Fig. 1). This enables a holistic and more unified perspective of the phenomenon, in an incipient literature which has remained fragmented. We thus contribute to this literature, moving beyond anecdotal discussions, which do not allow the generalization of findings. The midrange theory that we develop in the form of a phenomenological framework, provides a conceptual guide for the development of new theoretical perspectives, and for researchers to undertake empirical observation and models to guide managerial practices.

Second, we extend the literature of frugal innovation to include the healthcare sector, and its agency. FIH impacts along both utilitarian and normative dimensions. Our study therefore contributes and adds breadth to the frugal innovation literature, which has witnessed rising scholarly interest phenomenon. Our theoretical framing also adds depth to the domain, where "frugal innovation is a descriptive notion" (Prabhu, 2017, p.5) and has been overwhelmingly empirical, and anecdotal. Furthermore, our study brings together strands of medical and management literatures, which have often stood apart in separated fields of knowledge, and thus we contribute by conversing with a broader and relevant audience.

Third, our study also initiates theoretical conversations around the role of cooperation in the development of frugal innovations, which has found only sporadic mention (e.g. Angot and Plé, 2015; Dahan et al., 2010; Sarkar, 2021; Sarkar and Mateus, 2022; Sharmelly and Ray, 2018). While conventional innovations are exhorted to adopt a more "open" approach (Chesbrough, 2003), FIH involves important collaborative aspects as a key part of its development process.

Fourth, by exploring the FIH phenomenon we provide strongly supported suggestions of "what richer countries can learn from poorer ones" (Crisp, 2010). Recently, scholars have expressed concern for management to move away from a Western-centric development that has dominated management and organizational studies (e.g., Bruton et al., 2021; Muzio, 2022). The FIH phenomenon we draw attention to, as well as the FI on which it is embedded, illustrates such a movement. The phenomenological framework that we propose, can serve as a base on which future scholars can base their theoretical and empirical considerations, not just of FIH, but other phenomena which emerge from resource-scarce settings.

4.2. Practical implications

There are also at least a couple of practical implications from our study. *First*, FIH shows how it is possible to develop ingenious, effective, and timely solutions to provide low-cost and appropriate healthcare solutions for both HICs and LMICs. FIH thus holds promise for policy makers around the world, so that they can consider these low costs, as part of RI healthcare solutions, echoing a call by the World Health Organization which has appealed for the development of innovative and low-cost interventions (WHO, 2020b). With governments and firms in developed regions being continually pushed to be innovative (Gil-Garcia et al., 2014), constrained fiscal situations of governments emphasize how frugal innovations are a way to cope with reduced public spending (Singh et al., 2012). Since healthcare is a major expense category for all countries, understanding how FIH can be integrated in healthcare systems is of special interest that can help lower healthcare costs. Our study can thus be a starting point to initiate conversations, especially in more developed countries where the use of FIH is still scant. Hopefully, introducing FIH products in the healthcare could in the long term also help reducing the out-of-pocket expenditure for citizens which is important since low incomes are associated with poorer health status, higher morbidity and mortality (Subramanian and Kawachi, 2004).

Second, our study highlights the cooperative aspect of working across sectoral boundaries to achieve common goals. Successful cooperation implies a complementarity of parties in terms of resources and expertise. Cooperation gains further importance as acceptability is one major challenge of FIH and as healthcare system panoramas are so diverse across the globe. Therefore, cooperation between developers and target users such as medical teams may be essential to assure the adherence of FIH in the target markets. While cooperative actions tend to be temporary, we suggest that the development of FIH products necessarily implies a strong collaborative link, as its success depends on the involvement of multiple actors.

Third, by gathering successful examples of FIH and exploring the antecedents, processes, and outcomes. Inherent to these in a phenomenological form, moving away from the idea that FI implies cheap and low-quality products, we also intend to incentivize ventures which can find inspiration in this phenomenon to engage in such frugal approaches and RI as well. As we have seen, FIH can be achieved by both applying simple and low-cut technologies and more sophisticated ones, opening up the opportunity for diverse types of ventures to develop FIH which can further contribute for the improvement of healthcare systems.

4.3. Social implications

The outcome dimensions that characterize FIH, suggest a variant of the two-pronged approach of utilitarian (i.e., economic, product oriented) and normative (i.e., social) aspects. As with any other venture, maintaining financial sustainability by pursuing profits remain an objective, while a social outcome is associated with the improvement of healthcare provision in an affordable way, to many who would otherwise have been without such healthcare solutions. For instance, by developing portable and robust diagnostic and other tools which can be operated by non-skilled personnel and be transported to remote areas where these services are not available, ventures can profit from those underexplored markets while providing people the chance to be diagnosed and treated for diseases which could otherwise cause severe health consequences.

The COVID-19 pandemic provides opportunity to look at healthcare solutions with fresh eyes, where in doing "more with less" may lie the answer we are searching to solve some of the inefficiency and accessibility issues in healthcare. This context also provides an opportunity to move beyond conversations among researchers and innovation practitioners, but also penetrate the broader society, breaking the stigma around barriers for low-cost solutions, This may extend from the healthcare field to other fields where high-end and expensive technology has been considered the only option, often increasing global social inequalities.

5. Limitations and future research directions

This study has a few limitations, calling for some caution to be exercised in generalizing our findings. First, as in all narrative reviews there is some degree of subjectivity. We have tried to limit such subjectivity by keeping a broad scope and searching for literature and cases in a systematic way to avoid missing important information. A systematic literature review will be called for once more substantial literature is available.

Second, the healthcare is unique in the intimacy, complexity, and sensitivity of the services it provides (Macrae and Stewart, 2019). Healthcare is also enormously varied, and care must be exercised when extending theories and understandings from management literature to the healthcare sector. As Vincent and Amalberti (2016) pointed out, healthcare is better understood as perhaps twenty different industries. Thus, while we propose mechanisms of the FIH phenomenon, as in all theoretical and conceptual developments, these are higher order understandings, and in healthcare in particular, our framework may not be easily and directly transfer to all healthcare settings.

Furthermore, while we made the conscious decision to only explore FIH products, we realize that it is relevant to explore the remaining types of FIH (service, process and business model) more deeply, both through case studies and conceptual work. FIH models exist, for instance, the classical example of the Narayana Hrudayalaya Hospital in India which

provides "world-class yet cost-effective cardiac care by applying the principles of lean manufacturing and mass production" (Khan and Melkas, 2020, p.168), enabling poor people to have free or low-price access to quality healthcare while the hospital still attains high profit margins from richer patients. Understanding the organization of this and other examples (Cicellin et al., 2019) may be an important step for healthcare systems in both LMICs and HICs to be inspired in their mission and *modus operandi* aiming at increasing their services efficiency while expanding their reach to more underprivileged population.

We did not explore the reasons behind the fact that HICs are more reluctant, although increasingly less, to adhere to FIH. Although we believe cultural and institutional factors may be limiting factors, it would be interesting to explore this venue, contrasting these and other realities with the ones of environments which welcome FIH, so that governments and other entities may be informed of the benefits and underlying enabling mechanisms of FIH to improve healthcare access and affordability.

While these noted above limitations in turn provide opportunities for further research, interested scholars can further explore other fruitful avenues. One interesting aspect, to which we did not find enough evidence, is regarding the effect of FIH in the lowering of competitor products' prices. This was observed in the case of the TTK-Chitra heart valve, where the price of the previously imported valve which was standard to use was reduced by 50 per cent after the frugal valve was commercialized and made popular (Valiathan, 2018). In the future, it would be interesting to explore this effect, as it may contribute to further understand the outcomes of FI, both in healthcare as well as in other sectors. Also, regarding the more utilitarian (economic) outcome of FIH, there is an opportunity to explore the profitability differences between ventures which engage in FIH in comparison to the more traditional research and technological-led innovation processes. This is still an underdeveloped topic in FI literature which tends to focus more on the social outcomes of such processes.

Moreover, we have focused primarily on FIH, and while we did discuss RI, it is an area of enormous interest in the healthcare sector in HICs, given the promise it holds of affordability as well as functionality. RI is a promising area to explore in the healthcare sector, for instance, trying to understand which are the distinctive features of frugal products in healthcare that make them eligible for RI. Moreover, relevant practical and policy implications can arise from understanding and predicting the effects of employing a frugal mindset and using frugal products in healthcare services in HICs. In summary, one can more deeply explore how FIH and RI can contribute to achieve United Nation's SDGs such as SDG 3: "Ensure healthy lives and promote well-being for all at all ages", SDG 10: "Reduce inequality within and among countries" or SDG 12: "Ensure sustainable consumption and production patterns" (United Nations, 2020).

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Declaration of competing interest

None.

Appendix A. Examples of studies containing information on cases of FIH

Authors, date	Title	Source
Agarwal et al. (2021)	Constraint-based thinking: A structured approach for developing frugal innovations	IEEE Transactions on Engineering Management
Bhatti et al. (2017)	Global lessons in frugal innovation to improve health care delivery in the United States	Health Affairs
Bianchi et al. (2017)	Healthcare frugal innovation: A solving problem rationale under scarcity conditions.	Technology in Society
Corsini et al. (2020)	Frugal innovation in a crisis: the digital fabrication maker response to COVID-19.	R&D Management
DePasse and Lee (2013)	A model for "reverse innovation" in health care	Globalization and Health
Grover et al. (2014)	Frugal innovation in healthcare and its applicability to developed markets	British Academy of Management Conference Proceedings (2014
Gupta and Thomke (2018)	An exploratory study of product development in emerging economies: evidence from medical device testing in India.	R&D Management
Harris et al. (2020)	Fast and frugal innovations in response to the COVID-19 pandemic	Nature Medicine
Hossain (2017)	Mapping the frugal innovation phenomenon	Technology in Society
Lim and Chia (2016)	Social entrepreneurship improving global health	Journal of the American Medical Association
Mandal (2014)	Frugal innovations for global health - Perspectives for students	IEEE Pulse
O'Hara (2015)	Is safe surgery possible when resources are scarce?	BMJ Quality & Safety
Prime et al. (2017)	Frugal and reverse innovations in surgery	Global Surgery: the essentials (book)
Steyn et al. (2020)	Frugal innovation for global surgery: leveraging lessons from low- and middle-income countries to optimize resource use and promote value-based care	Bulletin of The Royal College of Surgeons of England
Valiathan (2018)	Frugal innovation in cardiac surgery	Indian Journal of Thoracic and Cardiovascular Surgery
Vesci et al. (2021)	How to save the world during a pandemic event. A Case study of frugal innovation.	R&D Management
Winterhalter et al. (2017)	Business models for frugal innovation in emerging markets: The case of the medical device and laboratory equipment industry	Technovation

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