How does frugal innovation emerge and lead to sustainability in developing countries? A case study in Malian agricultural areas.

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Abstract

We analyze a case of frugal innovation. We look at the innovation process that led to the creation of a motorized seeder in Mali to face the climate change, and we explore its antecedents, enablers and consequences. Thanks to an in-depth qualitative case study and literature review, we analyze our case with the purpose of better understanding the process itself and the elements that play a key role. After having discussed what frugal innovation is and how it relates to sustainability, we develop several contributions. Firstly, we open the *black box* of sustainable frugal innovation process. Secondly, the paper shows particularly how antecedents such as resources scarcity, institutional voids, and social problems, are considered in the whole innovation process. A third contribution is to put into evidence the importance of bricolage, frugality and eco-friendly practices, as well as the key role of collaboration, as crucial enablers and as key mechanisms in the innovation process. Finally, our analysis of the main impacts of sustainable frugal innovation in the context of our case allows to advance the debate of innovation for sustainability (economically, socially and environmentally), in addition its impacts in terms of reinforcement of market institutions, continued collaboration and customers consumption behavior (e.g. co-consumption). We conclude our contribution by proposing a model taking into account the different elements identified through our study.

Keywords: sustainable frugal innovation, frugal innovation, sustainable innovation, sustainability, farm mechanization, developing countries

1. Introduction

Agriculture appears to be the pillar of many African developing economies, employing more than two thirds of their active population (FAO, 2016). Simultaneously, agricultural systems often fail to meet the needs of low-income populations in developing countries, especially in the context of climate change. As result, this population is at the bottom of the pyramid (POB)[2] and, consequently, not targeted by the suppliers of modern equipment and farm inputs.

[2] According to Prahalad (2005), the large part of the world population is at the bottom of the pyramid, i.e. a segment who is very poor and living on less than $2 a day. It has been pointed out that over 2.5 billion people live on less than $2 per day (Prabhu et al., 2017).

Accordingly, developing local, affordable, sustainable, and user-oriented farm technologies and services remains a priority to fight against hunger and poverty. Especially since previous mechanization and modernization races undertaken by some African governments have led to huge expenses in equipment that remained unused as it was not adapted to the field reality (FAO, 2008). Innovation seems to be the process to follow in developing world (World Bank, 2011; Worldwatch Institute, 2011), but not just any. Authors currently agree that alternative innovation types have to be designed to ensure their impact when resources are scarce and institutions are weak (Prahalad, 2005; Prahalad and Mashelkar, 2010; Sharma and Iyer, 2012; Radjou et al., 2012; Annala et al., 2018). Following those authors, those innovation types, generally named frugal innovations, aim at *doing more with less*, under difficult conditions, to serve a large part of poor population. With respect to that, this new innovation paradigm is clearly different from the conventional Western innovation paradigm, where important research and development investments are supposed to maximize return on investment and growth. The theorists of this new paradigm propose, on the contrary, point out that constrained environments can be an opportunity for innovation (Prahalad, 2005; Radjou et al., 2012).

Very recently, Pisoni et al. (2018) have conducted a systematic review of frugal innovation. They explored how the frugal innovation concept was developed by scholars in the last years. We agree with them that the frugal innovation topic has been addressed around some main issues such origins and definitions of frugal innovation, the characteristics of resource-constrained environment where it emerges, its process and crucial enablers, as well as its impacts. Despite the importance of the frugal innovation topic in literature, it remains theoretical, and its relationship with sustainability is limited or not fully clear. Thus, we will specially focus on the term sustainable frugal innovation (SFI) in this research.

In this paper, we illustrate the process of SFI by studying an innovation case concerning a mechanization project in the agricultural sector in Mali. This project was a collaboration between a national research organization, local farmers, and local small entrepreneurs, as well as technical and financial partners in Mali. To analyze this case, we have chosen a qualitative methodology based on interviews with the different stakeholders. Through this case, we try to understand SFI through the analysis of its antecedents, enablers and consequences.

The paper is organized as follows. In the first section, we present the background of frugal innovation, and its links with sustainability. The second section is devoted to the presentation of the research framework. After, comes the research gap. The fourth section briefly describes our methodology. We develop the main results in the fifth section. Finally, we conclude with

discussion, implications for academics, managers and policy makers, and suggestions for future research, as well as the limitations of our research.

2. Background

This section provides an introduction to the concept of frugal innovation and its possible links with sustainability.

2.1. Frugal innovation

The interest for alternative innovation types for and from developing countries has raised in the literature, with examples (*see* Sharma and Iyer, 2012; Tiwari and Herstatt, 2012a) coming from a variety of fields and industries: agriculture (M-Farm mobile applications in Kenya, solar irrigation pumps in Bangladesh, mini-tractors in India), health (electrocardiogram system in India), automobile (Tata Nano low-cost cars in India), mobile banking (M-Pesa in Kenya, Orange money and Mobicash in Mali). The increasing interest for those alternative innovations has also led to an avalanche of concepts such, Bottom Of Pyramid Innovation (Prahalad, 2005), Grassroots Innovation (Dey and Gupta, 2016), Cost Innovation (Williamson, 2010), Frugal Engineering (Radjou et al., 2012), Frugal Innovation (Zeschky et al., 2014), Jugaad Innovation (Radjou et al., 2012), Inclusive Innovation (George et al., 2012), and Resource Constrained Innovation (Sharma and Iyer, 2012), etc. Previous studies (e.g., Prabhu, 2017; Bhatti and Ventresca, 2013; Zeschky et al., 2014) argue that the term frugal innovation should be viewed as a label of these terms because all related terms describe essentially a similar phenomenon (constrained environments). The concept of frugal innovation seems sharing many of characteristics (e.g. low price, small use of inputs, reuse of existing components, easy to use, etc.) with those other concepts (Tiwari and Herstatt, 2012b).

In definitive, the philosophy of frugal innovation is based on the transformation of scarcity into competitive advantage through frugality, flexibility, ingenuity and inclusiveness (*see* Radjou et al., 2012; Prabhu and Jain, 2015), as well as simplicity, quality, multi-functionality in new products and services (Sharma and Iyer, 2012; Ernst et al., 2015). Ernst and Young (2011) define frugal innovation as an economical use of resources to provide products affordable by those on a lower income. Frugal innovation concerns multiple innovators such as, individuals, local firms, public organizations, multinationals, etc. It very often involves the development of technological products or services. In addition, if endorsed by actors from developing countries, this approach can contribute to tackle brain drain experienced by those countries. Other scholars

point out that frugal innovation can emerge in developed countries for their own specific growing markets (*see* Pisoni et al., 2018).

Despite the attention it has received, frugal innovation remains an emerging topic and deserves more research. It is recognized that frugal innovation research shares many similarities with research on sustainability (Prabhu, 2017). We explore those connections in the following subsections.

2.2. Sustainable frugal innovation (SFI)

Due to increased social inequality and environmental damage, policies call for sustainable development in the world, "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). In the same way, Geissdoerfer et al. (2017) defined sustainability as "the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations". This kind of innovations must reduce resource, energy, land use, and emissions and waste, etc. during the production and the consumption phase (Bocken et al., 2014). Thus, the challenge of sustainable development has conquered the core of the frugal innovation in developing countries in response to poverty, food insecurity and climate change. To study SFI, sustainability research streams can be relevant. Socially and economically, frugal innovation tends to be inclusive (George et al., 2012) by serving a large numbers of low-income people, who are often excluded of the formal market (Prabhu and Jain, 2015). According to George et al. (2012), inclusive innovation is defined as "the development and implementation of new ideas which aspire to creating opportunities that enhance social and economic well-being for disenfranchised members of the society". For instance, Christensen et al. (2006) think that inclusive or catalytic innovations can reduce worldwide inequalities by focusing on various areas, such the economy, health, education, etc. In sustainability perspective, practices of frugality becomes necessary to avoid excessive and unfair consumption by intentionally turn actions to social and ecological conditions (Nash, 2000; Pepper et al., 2009). While the populations are huge, and resources are scare it is essential to implement sustainable practices, e.g., using recycled materials in the design and production (Radjou and Prabhu, 2015), and into new product development process (Sharma and Iyer, 2012). Those authors argue that one of the fundamental principle of frugal innovation is to bring sustainable solutions, “which could be shared, reused, customized as well as offering more to cheer for the customers and also saves a lot when it comes to costs and the environment”, in developing markets. Frugal innovation definitely reduces the use of financial and natural

resources in the innovation process, in developing countries, and create value for customers, partners, and society (Rosca et al., 2017).

Only a few studies address empirically frugality and sustainability in innovation process. In India, Annala et al. (2018) tried to understand the case of low cost household waters filters innovation among local small scale entrepreneurs and end users interactions. They stipulate that the active participation of the end users as co-producers in frugal innovation process in order to meet users' needs and price expectations. These authors showed that frugal innovation can be ecological clean, affordable, and assures social impacts in resource-constrained environments. In addition, Rosca et al. (2017) have focused their research on business models of frugal innovation in BOP markets and their potential for economic, social ecological sustainability outcomes. Finally, Pansera and Sarkar (2016) examine frugal innovation process at grassroots level in developing countries. They suggest that grassroots innovators cannot be only co-producers but producers of frugal innovation for social and environmental sustainability.

In this study, we use the term sustainable frugal innovation (SFI) regarding frugal innovation for sustainability. We define SFI as the development or adaptation of products and services, under the resource constraints (e.g. financial, human and natural) in the innovation process, with the aim to satisfy the social needs of low revenue and non-served populations. Such innovation emerges generally from the collaboration between multiple actors, and it is essential to maintain the collaboration over time for more efficiency. In a context of globalization, those actors can come from developing countries, as well as developed countries. Thus, we consider SFI as an inclusive process of innovation that promote social, economic, environmental sustainability and continue collaboration, and enhance market institutions. It is recognized that such systemic innovation leads to sustainable growth (Prabhu, 2017). Previous studies (Rosca et al., 2017; Shivdas and Chandrasekhar, 2016) have mentioned SFI, without define it clearly. However, Pansera and Sarkar (2016) defined sustainability-driven frugal innovation as "the desire to generate solutions designed to minimize the impact on the environment, combined with the scarcity of material and financial resources, it leads to the development of more energy/material efficient solutions".

3. Research framework

Drawing on the theoretical and empirical literature on frugal innovation, and sustainability, the main supports regarding our research question were identified. To answer how frugal innovation emerges and leads to sustainability, we found relevant to explore in-depth three

elements which characterize the innovation process: antecedents, enablers or crucial practices, and outcomes, which are mentioned as relevant issues in Pisoni et al. (2018) systematic review about frugal innovation.

3.1. Antecedents

Constrained environments make developing economies in Asia, Latin America and Africa an ideal context to rethink the paradigm of innovation. Most people in developing economies have low revenue, and work in the informal sector (Sheth, 2011; Prahalad, 2012). In view of those situations, the new paradigm of innovation suggests that constrained environments provide an opportunity for innovation (Prahalad, 2005; Radjou et al., 2012). Several recent studies have considered constrained environments as drivers of frugal innovation in developing economies (Sharma and Iyer, 2012; Bhatti and Ventresca, 2013; Pansera and Owen, 2015). Our understanding of constrained environments includes resource constraints, institutional voids and social needs (i.e., basic needs such as food, health, education, energy), which better characterize developing economies.

3.2. Crucial enablers and practices

Ernst et al. (2015) identify three practices for affordable value innovation: bricolage and local embeddedness, and standardization. Ernst et al. (2015) have also found that bricolage allows to combine existing resources in new and creative ways in order to face lack of resources, and local embeddedness gives them the collaboration possibility (with local partners) to overcome the lack of institutions and avoid market failure. Tiwari and Herstatt (2012b) put into evidence collaboration at all phases (initiation, development and diffusion) of frugal innovation process in India. Accordingly, in this study, we consider bricolage, frugality practices, eco-friendly or environmental sustainability practices, and collaboration as main enablers of frugal innovation.

3.3. Consequences

As already described, scholars have paid attention to impacts of frugal innovation for low income customers in developing countries. Constrained environments offer the opportunity to develop and distribute innovations and green solutions in order to optimize sustainability impacts (Prahalad, 2005; Sharma and Iyer, 2012; Brem and Ivens, 2013; Levänen et al., 2016; Hyvärinen et al., 2016; Rosca et al., 2017), economically, socially, and environmentally.

4. Research gap

Scholars are only beginning to be interesting in innovation for and in developing economies, and remain largely based on India or China. While interesting, existing studies are mainly

theoretical, market-oriented, or present the frugal innovation process as *black box*. Therefore, they look at antecedents, enablers and consequences separately. Thus, they neglect to integrate these key elements together for a deeper understanding of frugal innovation. In this study, we try to operationalize the three elements and its attributes. In contrast, this research will explore SFI in Africa. To the best of our knowledge, this study is one of the first ones to open and explore the *black box* of SFI, especially in Africa (*see* also Wooder and Baker, 2012). While prior studies on frugal innovation are often firms-based views (focused on MNCs' innovations), this research analyses a case of innovation project including a local public research organization, customers (farmers) and local small entrepreneurs (blacksmiths), NGOs and foreign partners, in the sector of agriculture in Mali. Our innovation case is expected to be associated with the integrated perspective of frugal innovation and sustainability.

5. Methodology

Our empirical study uses a qualitative exploratory methodology. We first present the research context, then we develop our research strategy. Finally, we briefly present the case and the data collection modalities.

5.1. The context of farm mechanization in Africa

In Africa, agriculture is mainly rain-fed. Consequently, this sector is impacted by climate change, farming performances being strongly correlated with rainfall (Sultan et al., 2015). Additionally, rapid population growth and increasing urbanization in Africa raise the challenge to improve farming productivity, not only to ensure food security, but also to meet the requirements of urban markets, which generate higher revenues for farmers. To face those challenges, African farmers expect a lot from technological innovations in the fields of farm mechanization and modernization (Pingali et al., 1987; Houssou et al., 2014). With mechanization, farmers can gain much more work power, increase the productivity and time efficiency of field operations (Cerutti et al., 2014). According to FAO (2013), mechanization technologies from developed countries are more and more sophisticated, less and less affordable and not profitable for small African farmers. Adekunle and Oluwatosin (2015) add that farm mechanization in the 21st century should be simultaneously compatible with the environment, economically viable, affordable and adapted to local conditions. These technologies should be more frugal, sustainable and convivial that could fit the needs of customers in poor countries, rather than those who use a lot fuel (Gomiero, 2017).

Consequently, we are convinced that the context of farm mechanization in Africa is very interesting to study SFI. Through our case study in Mali, we could thus contribute to a better understanding of agriculture mechanization in developing countries and to research on SFI.

5.2. Research strategy

Our exploratory research uses a qualitative approach centered on a case study, as formalized by Yin (1989). The case study strategy seems relevant for our research purpose. Following Hlady-Rispal (2002), "the exploratory case study aims at understanding one or several management situations and analyses them in detail […]". As a matter of fact, exploratory method allows the emergence of new elements to better understand the studied phenomenon. Our case study will give us the opportunity to understand in depth, explain and illustrate the phenomenon linked to SFI and does not generalize theory or results.

5.3. Case study presentation: the motorized seeder

In this research, the case was chosen because of the nature and the newness of the innovation (Habib, 2010; Gurca and Ravishankar, 2015). The motorized seeder is the result of a collaboration between the IER (Institute for Rural Economy of Mali), the project leader, NORAGRIC (International Environment and Development Studies, Norwegian University of Life Sciences), GCOZA (Coordination Group for Arid Areas), farmers (users) and local small entrepreneurs (blacksmiths), in the context of a project named "development of technical options to adapt agriculture to climate change".

Figure 1. ***Motorized seeder for fertilizers and seeds***

The project is linked to the context of farm mechanization that was developed earlier. It follows previous works of IER, since 2006, concerning mechanical distribution of micro-doses of seeds and fertilizers. The motorized seeder technology was developed to reduce farm hardship and to

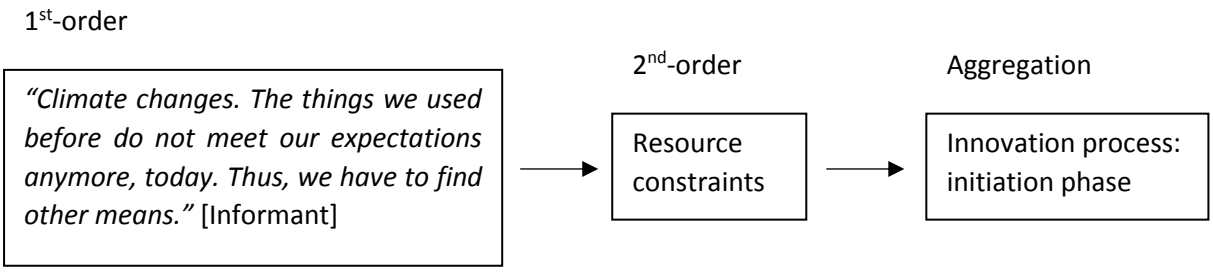
improve production and productivity of cultures in the context of climate change. The project lasted 5 years from June 2010 to June 2015. It included research, development and diffusion of prototypes of motorized seeders.

5.4. Data collection and analysis

In this research, we used three data sources: semi-directive interviews, documentation and observation. This supports data triangulation (Yin, 2009). To collect data, we contacted stakeholders who were directly involved in the project, as well as some experts of farm mechanization in Mali. The individual interviews involved researchers (IER), NGOs members (from ADRA Mali and ADAF/Gallé), members of GCOZA, experts and farmers, and were generally conducted in Bamako and in the area of Kati. Nevertheless, due to the rainy season, three interviews were performed by phone. In total, we led 24 interviews (13 farmers, 2 researchers, 5 experts and 4 NGOs agents) from August 2016 to January 2017. The interviews took between 30 minutes and 90 minutes. We also collected documents as activity reports and evaluation reports of the project. We completed this information by on-site observations at the farmers' places.

The interviews were transcribed, coded and analyzed (*see* appendix). We used NVivo, software for textual data analysis, which makes data analysis more easy and systematic (Sinkovics et al., 2014). In the data analysis, we drawn on the method proposed by Gioia et al. (2012). Other works in management of frugal innovation literature have pointed out the fruitful and robust characteristics of this method for theories validation or building (Pansera and Sarkar, 2016; Pansera and Owen, 2016). Following those authors, the analysis was organized in two main stages. First, we created a data structure with respect to our research subject, and then, we discussed about the theoretical elements that emerge from this structure. Especially, the data structure included three main levels: informant terms (1st-order), theoretical emerging themes (2nd-order) and aggregate level.

Example from the data structure



The results put into evidence the elements characterizing antecedents, enablers and consequences of SFI, as they appeared in the interviews. The following table summarizes the obtained results (*see* appendix for details). Finally, on the basis of our empirical results, we propose an extended model of SFI.

Summary table and model

Table 1. Antecedents, enablers and consequences of SFI, from the case of the motorized seeder

		ANTECEDENTS		
		Resource constraints	Institutional voids	Social needs
Constrained environments		Financial Natural or environmental (*rains*) Human Material	Breach of contracts and rules => trust crisis Exclusion Lack of vision Weak State power	Problems of low revenues and foods insecurity in rural areas in developing countries
		ACTIVITIES AND ENABLERS		
Innovation process	Initiation	Identification of needs and expectations	Identification of needs and expectations	Interactions with farmers
	Development	Reduction, Recycled and Reused of resources use Bricolage Mutual learning Farmers capacity building	Trust Actors' roles and responsibilities	Seeking partnerships Farmers experimentation Co-development (farmers, manufacturers, NGOs, donors)
	Diffusion	Donations to some first adopters Farmers capacity building	Proximity of manufacturers (local production, service provision)	Co-consumption Co-diffusion (farmers, manufacturers, NGOs, donors)
		CONSEQUENCES		
Outcomes		Economic: affordability, cost minimization, use utility, multi-functionality		
		Social: youth employment, female farmer empowerment, household and social cohesion, feeling of social progress		
		Environmental: recycling facility, fuel-efficiency, lower soil degradation, use of micro-doses technique		
		Institutional: norms respect, trust building, accessibility		
		Collaborative: interaction, openness, network (local small entrepreneurs, NGOs, research organizations, etc.)		

The previous table and the results that we obtained through our case study lead us to propose a model of SFI, refining the previous proposals from the literature. In particular, we open the *black box* of the innovation process and we underline the importance of enablers at every step of the innovation process, and we identify some antecedents and consequences of this process. This model is proposed in Figure 2.

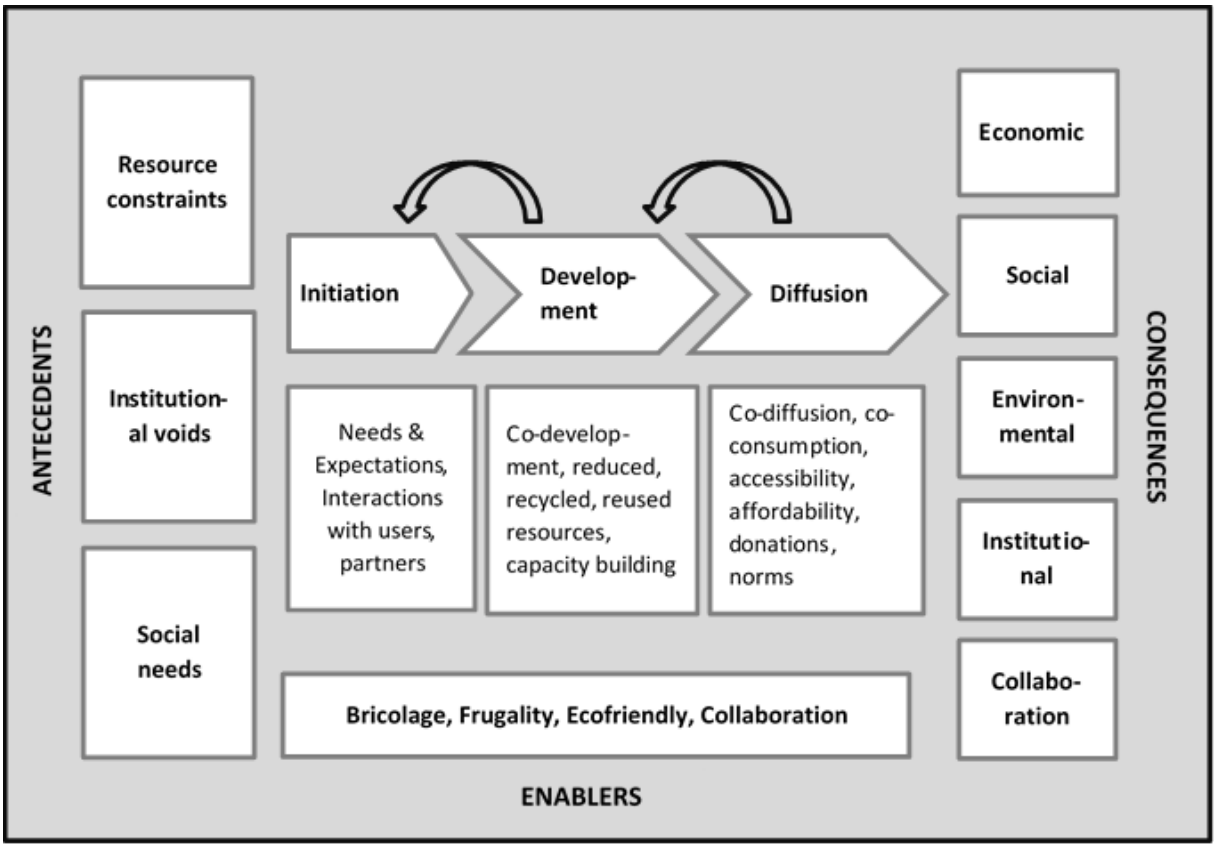


Figure 2. Proposition of a model for SFI

6. Discussion and conclusions

Our study is in line with prior research (Rosca et al., 2017; Sharma and Iyer, 2012; Shivdas and Chandrasekhar, 2016) and contributes to the literature on frugal innovation and innovation for sustainability. Empirical studies on frugal innovation are practically nonexistent, the main works are linked to the Indian context, and often focused on firms' innovation perspective (Cunha et al., 2014) or individual and small community grassroots innovations' view (*see* Pansera and Sarkar, 2016). An in-depth qualitative case study investigated in Malian agricultural sector can be relevant, given the growing interest for the African markets in a context of globalization. This case study concerns a project innovation where multiple actors were involved, including research institute, a foreign partner, NGOs, farmers and local small entrepreneurs.

This research is also an answer for Pisoni et al. (2018) call to study the whole frugal innovation process. Until now, most research has considered the process of frugal innovation as a *black box*. Our study is an initial attempt to analyze the whole innovation process of SFI. In this paper, we extend existing research by proposing a conceptual model that contributes to a clearer understanding of how SFI emerges and leads to sustainability. Thus, this paper serves to better

reveal the antecedents, enablers and consequences of SFI. We also expanded the definition and the understanding of frugal innovation through sustainability considerations.

Particularly, our findings make some important contributions to the literature.

As antecedents, we confirm findings of prior research that SFI emerges from constrained environments, and social needs. The paper shows particularly how the antecedents: resources scarcity, institutional voids and social problems or needs are considered in all the innovation process. To face those problems, innovation process, revealed non-linear, requires different activities and enablers.

The paper thus shows how bricolage and collaboration, as well as frugality and eco-friendly practices, can be crucial enablers for SFI. In respect to Gurca and Ravishankar (2015), the study illustrates how different types of bricolage activities relate to the development of SFI in constrained environments. We found that bricolage activities, frugality practices (using of less, recycled and reused resources) and eco-friendly practices can be aligned.

The paper also shows how various types of collaboration (interactions for idea generation, co-development and co-diffusion) relate to different phases of innovation process and to different types of stakeholders. We show that collaboration in constrained environments allows access to foreign partners and NGOs financial and technical resources, farmers' informations, experimentations and feedbacks, local small entrepreneurs' skills and proximity, and leads to mutual learning, capacity building and trust reinforcement. The relevant role that the innovation promoter play in SFI process is also another contribution of this paper. He is the central actor in the innovation project.

Finally, our understanding of what are the main impacts for SFI allows to advance the debate of innovation for sustainability (economically, socially and environmentally) as well as the survival of innovation in constrained environments in terms of reinforcement of market institutions, continued collaboration and customers consumption behavior (e.g. co-consumption).

Our study has also important implications for innovation managers as well as for policy makers. In terms of implications, this study provides more details to managers that would like to conduct or implement an innovation project in constrained environments. The research suggests that the managers should seek to combine different local resources and skills, and global collaboration in order to satisfy social needs of neglected population. Given importance of developing

markets, local entrepreneurs and firms as well as multinational companies can play a crucial role for promoting SFI and enhance competitive advantage. Some Asian MNCs are already present on these markets, for instance in telecommunication or motorcycle domains. They must be encouraged for a better integration of sustainability dimensions and be interested by light mechanization in agricultural and foods sector. In developing countries, it is important to note that resources scarcity and institutional voids should not views as barriers but as the way to stimulate creativity, innovation (Cunha et al., 2014), and to gain new market opportunity.

Given the strategic importance of innovation in growth, especially in agricultural and foods sector, in developing countries as Mali, the policy makers can play a key role in terms of infrastructures (roads, electricity) (Prabhu, 2017) to facilitate farmers or transformers market access. It could be also relevant to bring frugality and sustainability practices in public research centers. Our case study show how a public research organization deliver a SFI with its partners, farmers and local small entrepreneurs. In this respect, policy makers can create opportunities for local entrepreneurs and response to social demands. According to Hall et al. (2018), it becomes particularly pertinent for public research labs and universities to be a driver of sustainable technologies for local entrepreneurs and firms in constrained environments. Finally, policy makers can also continue encouraging co-consumption (equipments sharing in rural areas) perhaps through farmers organizations. We believe that SFI can turn agricultural into a very attractive sector for many youth in poor African countries if the policy makers catch seriously this opportunity.

This study is not without limitations. They result mainly from the exploratory nature of qualitative research, and from the single case study. Despite the originality of our innovation case study in Malian agricultural sector, it is less generalizable. In addition, the fact that the seed machine is not freely commercialized yet, can be a limit for affordability issue. Future research could use a quantitative method to test attributes found regarding antecedents, enablers and impacts of SFI, and their relationship. It would be interesting to study this concern from multiple case studies, across different sectors or countries. It is also necessary to take into account the cultural factors of context where SFI occurs. Finally, in this context of multi-actors collaboration and multi-sourcing of components, future research could attempt to clarify the type or the owner(s) of intellectual property.

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Appendix. Extracts of interviews for qualitative analysis

Theme	Category	Verbatim (informants terms)
Constrained environments (Antecedents)	***Resource constraints**:* financial, natural or environmental, human, material ***Institutional voids:*** breach of contracts and rules, trust crisis, exclusion, lack of vision, weak State power ***Social needs:*** Problems of low revenues and foods insecurity in rural areas in developing countries	*"Climate changes. The things we used before do not meet our expectations anymore, today. Thus, we have to find other means."* [Farmer_Other.8] *"The great farm mechanization failed because there was no stuff focused on the real needs of farmers. They introduced machines, they introduced tractors (…). Additionally, this failure is due to a lack of maintenance and repair of this equipment. For instance difficulties to find spare parts or qualified workforce…"* [Expert.2] *"When there was still a State, every equipment was experimented by users before introduction into farms, or at least tested and approved by our service. Nowadays the State does not back anything (…). We need human resources and adapted equipment."* [Expert.4] *"Concerning equipment policy, the State advances through isolated measures but there is no real mechanization policy. This explains partly the weak mechanization in Mali."* [Expert.2] *"When the season starts, people are faced with skinny oxen and with massive departures of valid people. People who cultivated 20 Ha are left with less than 5 Ha. Before, even if the children set out on an exodus, they came back with the rainy season. Now they don't come back anymore. (…) If this goes on like this, the agricultural world will collapse. We have to bring in more convenient technologies."* [Member_R&D.2] *"Isolation and the electrification problem have also an import on agriculture. With electricity in rural areas, farmers could use a lot of machines as, very often, the provision of fuel is an issue."* [Expert.4] *"The State gave equipment and the bank funded it. (…) For loans, farmers deliberately don't pay. What do they say? 'In the next election, we shall blackmail them, if politicians do not erase our debts, we shall not vote for them.' All farmers' organizations are more or less politicized over there."* [Expert.1]

		"Clients don't really trust farmers, because when they conclude a contract, farmers then say afterwards that they don't have the products. (…) very often they are tempted to sell their products at the highest market process, even if they are bound by a contract." [Expert.1]
Innovation process for the motorized seeder and its enablers	***Initiation phase:*** identification of needs and expectations, scientists interactions with farmers	*"The idea arose due to a constraint that famers faced repeatedly: distributing seeds and fertilizers with micro-doses to face climate change. Using micro-doses helps to increase yield but it is fastidious. One hectare corresponds to 25000 holes if it is sorghum or mil, i.e. 15 km. If you have to put a pinch in each hole, it takes too much time and energy. Farmers complained. They say that they cannot spend thus much time putting pinches in holes. We had to find another way."* [Member_R&D.3] *"(…) by early season, oxen are undernourished and tired (…). Rains are no more abundant. So we have to adapt to climate change. This change pushes us to adopt faster technologies for farm works."* [Farmer_tester.2] *"Our famers have expectations. First [they need] technology put at the disposal of farmers. The technology must be productive, lucrative, easy to use and affordable at low prices. It must decrease time and hardness also. Finally, it must be adapted to the local environment."* [Member_R&D.3]
	Development phase: reduction, recycled and reused of resources use, bricolage, mutual learning, farmers capacity building, farmers experimentation, local practices, co-development (farmers, NGOs, manufacturers, donors), trust, partnerships, actors' roles and responsibilities	*"I hadn't got a lot of money. At the beginning, (…) I used one of my projects to do the first test (…). The first seeder (animal-drawn) that I brought on site for testing, I paid it out of my own pocket, with my salary. Afterwards, partners gave funds."* [Promoter] *"We paid a lot of visits. To determine the quantity of micro-doses, we took the pinches of the farmers. First the seeds alone, then with the fertilizers. This is what we translated into the machine."* [Member_R&D.1] *"You have the blacksmiths who were trained progressively, whose children picked up the burden. When we started to reflect on motorization, we hired a blacksmith (…). We discussed with him and we made a design. We looked at the size of engines on the market. We first did the job in the forge."* [Member_R&D.1] *"We recycled old motorcycle tires to protect metallic wheels, we reused construction scrap."* [Member_R&D.1]

Innovation process for the motorized seeder and its enablers		*"We set up and supervise experimentations, and we advise users. The experimentation plots are in the fields of the participating farmers. We collect information, farmers' viewpoints concerning those technologies. We intervene to facilitate extension of this equipment."* [Member_NGO.2] *"To understand some phenomena, we need to go to bed at night to try to see the reasons. I am learning by doing, on the field (…). To reinforce the capabilities of the farmers to work with technology, we took the hard core to train them (…). They can lead other farmers by example (…)."* [Member_NGO.1] *"The training that they provide us and the advices, if you respect them you'll improve your situation. Against climate change, pursuing with traditional practices would not be in our best interests."* [Farmer_Tester.1] *"First, participation is voluntary. Villagers know each other (…). So participants are chosen by the villages. They know how to provide open persons who will represent the village. They know who is likely to work long term. They [the chosen volunteers] are persons they trust."* [Member_NGO.1] *"You cannot fully understand a job without practicing. You cannot be convinced by a job without seeing the results (…). What you look for nowadays is to go forward, not to turn back."* [Farmer_Tester.2]
	Diffusion phase: donations to some first adopters, farmers capacity building, proximity of manufacturers (local production, service provision), co-consumption, co-diffusion (farmers, NGOs, donors, manufacturers,)	*"We shared our results with several projects and NGOs (…). We just sent 58 seeders to a partner (…). You need several years to have a feedback of [the results of] the equipment in the field (…)." [Member_R&D.5]* *"We draw upon those who will represent their village and will show the example to other farmers. When they adopt a technique, others will follow." [Member_R&D.2]* *"I never had my own seeder. I borrow the animal-drawn seeder of my brother to sow. Our father bought this seeder more than 30 years ago."* [Farmer_Other.7] *"That would be ideal if the associations could buy the machines and [allow them to] exploit them together (…)."* [Expert.5]

Impacts of the motorized seeder	***Economic impact:*** affordability, cost minimization, use utility, multi-functionality	*"The animal-drawn seeder asks for 1 man / day by hectare. With the hoe, it is equivalent to 8 to 12 men / day. With the motorized seeder, it is only 0.3 man/day by hectare."* [Member_R&D.1] *"With the new seeder, work time decreases, hardness diminishes and production increases."* [Farmer_Other.3] *"It is a time, energy and money saver. They save money for seeds and fertilizers, and for the maintenance of oxen."* [Member_NGO.3] *"One hectare in less than 2 hours, with less than 2 liters of fuel, which is the seeder."* [Member_R&D.2] *"I hope [that they will develop] mass production and that it will be available for everybody at affordable prices."* [Farmer_Other.8]
	Social impact: youth employment, female farmer empowerment, household and social cohesion, feeling of social progress	*"It is an opportunity for youth to start a business in the agricultural sector. It is a support for agricultural entrepreneurship."* [Member_NGO.3] *"We want to pursue change together, and that we will no more see those poor women bending their backs down to sow, weed. It is not about providing them tractors, there is lighter equipment."* [Expert.4] *"In our perspectives, we intend to make it accessible for physically disabled persons."* [Member_R&D.1] *"When you go to villages nowadays, young people, when they tell their story, you would be surprised. Because before a young guy was proud to say 'the whole day I beat everybody at ploughing'. Young men even got women for marriage because of that, because they were great cultivators. But now, young people think that that is being a bull and nobody was born to be a bull. This is because they have seen tractors, they have seen tillers, seeders (…)." [Expert.4]* *"With this seeder, if you are alone to sow, others can do other things. That is progress."* [Farmer_Tester.1] *"If the family is self-sufficient, it will prevent conflicts within it, decrease strains on the marriage."* [Farmer_Tester.4]

Impacts of the motorized seeder	***Environmental impact:*** recycling facility, fuel-efficiency, lower soil degradation, use of micro-doses technique	*"The seeder allows putting micro-doses of fertilizer. It allows using in the field just what is needed and to avoid to put too much of it. It is a light machine that exerts little pressure on the soil. (…) One hectare in less than 2 hours with less than 2 liters of fuel that is the seeder."* [Member_R&D.2]
	Institutional impact: norms respect, trust building, accessibility	*"The seeder is local. In almost all villages of Mali, there is a blacksmith who can manufacture a seeder (…). We identified the manufacturers who will be trained to ensure a manufacturing norm. Hence, you can find the same standard for all those manufacturers across Mali." [Member_R&D.1]* *"Thanks to the proximity of blacksmiths, farmers should no more walk long distances to be equipped." [Member_R&D.2]* *"One should ideally create small agricultural companies, provide them with that [the seeder] to provide services, as everyone cannot obtain it." [Member_NGO.3]*
	Collaborative impact: interaction, openness, network (local small entrepreneurs, NGOs, research organizations, etc.)	*"Research makes recommendations (…) to manufacture disks. Our blacksmiths don't have this information and don't master the concept of accuracy. The disk is manufactured with millimeter accuracy."* [Member_R&D.1] *"I wish that they don't let me down, that we can continue working together so I can acquire new knowledge."* [Farmer_Tester.4]