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The outward journey of a local innovation: diffusion of an artisanal irrigation pivot from the Algerian Sahara

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Abstract

User-led innovation is increasingly happening in a globalized context, connecting local experience to outside ideas, knowledge, and technologies. Alternatively, local innovations designed, manufactured and marketed for a particular context travel to other settings. We analyze the diffusion of a low-cost artisanal irrigation pivot from the Suf Valley (Algeria) to other Saharan regions and even to Saudi Arabia and Sudan. We conducted 27 semi-structured interviews with manufacturers, farmers, government agents, and made field observations on 18 farms in 2020/2021. The diffusion of the pivot was enabled by extending the innovation system to trusted innovation intermediaries in new settings, who played an active role in adapting the technology and support services to local agrarian systems. However, while the innovation homeland can be considered an open innovation environment, manufacturing and after-sales services in the new settings were tightly controlled by manufacturers to secure intellectual property and maintain a monopoly. This study contributes to the debate on the creativity of local innovation actors and their involvement in (supra)national agricultural development.

Keywords: Innovation, Outward diffusion, Adaptation, Artisanal pivot, Sahara, Algeria.

1. Introduction

Center pivots are a large-scale, sophisticated, and expensive irrigation technology invented in the arid American West (Waller and Yitayew, 2016). From the 1970s on, the technology was the center of considerable interest in North Africa and the Arabian Peninsula, particularly in countries with a substantial income from oil, in a quest to become self-sufficient or even net-exporters of foodstuffs. Governments of countries like Libya and Saudi Arabia, followed by Algeria,

were interested in using this technology to make the desert bloom (Pérennès, 1990; Dubost and Larbi-Youssef, 1998). The state-led promotion of large-scale irrigation technologies, accompanied by high subsidies for entrepreneurs to grow wheat, fodder, and other food products in these countries, has been strongly criticized as a “case of unsustainable development” (Elhadj, 2004). These critiques included environmental concerns, as (like oil), this particular agricultural development is based on the mining of non-renewable natural resources, particularly groundwater (Margat, 2008); social

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concerns, as this state-led development ignored existing peasantries with their long agrarian history of cultivating in extreme conditions (Otmame and Kouzmine, 2013; Bessaoud, 2021); and economic concerns, as this development model is only sustainable with generous subsidies (Elhadj, 2004). It is consequently not surprising that the technology was not widely adopted outside state-sponsored irrigation schemes.

A more stimulating development related to center pivots happened in the 1990s in the Suf Valley in south-east Algeria. Local artisans progressively developed low-cost small-scale center pivots by redesigning large-scale American center pivots that were unsuccessful in Algeria (Côte, 2006; Ould Rebai *et al.*, 2017). A single pivot in the Suf Valley typically irrigates one ha (versus around 50 ha for a standard center pivot) for the production of high added-value crops, mainly off-season potatoes, and costs only about US\$1,500. The technology was gradually stabilized over a period of ten years and became more effective through trial and improvement conducted in close collaboration between local artisans, traders and farmers using (and thus showcasing) these pivots on their plots. For all these reasons, this incremental innovation was very well received by local farmers and entrepreneurs and has accompanied a groundwater-based agricultural boom (Côte, 2006). In the Suf Valley, more than one million tons of potatoes, 40% of national production, are produced annually under 36,000 artisanal pivots (DSA, 2020).

Ould Rebai *et al.* (2017) showed the dynamics of the innovation system supporting the continuous development and adaptation of this artisanal center pivot. Innovation systems analysis allows to understand how a multitude of actors interact, exchange information and knowledge and develop, disseminate, and use innovations (Edquist, 2005; Ortiz *et al.*, 2013). In the literature, considerable attention has been paid to the strong points of user-led innovation systems (von Hippel, 2005), including their creativity and openness to variety, guaranteeing “the continual flow of new ideas and new sets of practices” (Rantisi, 2002); the strong implication of end users in the design of innovation, thus guaranteeing its adaptation to local conditions (Waters-Bayer *et al.*, 2009) and facilitating

user learning (Benouniche *et al.*, 2014). Such a user perspective partly explains the success of the artisanal pivot. Yet, it is equally important to view this development from a more institutional perspective, acknowledging the “rules of the game” regulating the “relations and interactions between individuals, groups and organizations” (Edquist, 2005, p. 183). In our case, this concerns the multiple interactions between local artisans – welders, fitters, electricians, mechanics, etc. – with different skills and know-how who manufacture the pivot, traders who procure a wide range of imported and recycled components of the pivot, farmers who use the pivot, and government agents interested in agricultural development. Inspired by the socio-technical analysis of Akrich *et al.* (2002), we analyze this innovation in the making by looking at the perspectives and practices of all actors interacting with the artefact, in our case the artisanal pivot. More specifically, we are interested in “the points of articulation between the object and the more or less organised interests which it gives rise to” Akrich *et al.* (2002, p. 205). One interesting feature of the pivot innovation system in this socio-technical perspective was how the intellectual property of the pivot was unlocked and shared among a wide range of actors, as multiple actors contribute to the ongoing improvement of the artisanal pivot (Ould Rebai *et al.*, 2017). The design of decrypted technology (Akrich *et al.*, 2002) by local actors has also been observed in the case of drip irrigation elsewhere in North Africa (Benouniche *et al.*, 2014; Naouri *et al.*, 2020).

Currently, there is a growing focus on connections between innovation systems at different scales (Fromhold-Eisebith, 2007), while recognizing that local innovation systems increasingly assemble not only local but also global actors (Naouri *et al.*, 2020). However, much less attention has been paid to how local innovations (ideas, know-how, technology), designed for specific local conditions, travel to other regions and how innovation systems handle such diffusion. Yet, in field visits to different Saharan regions in Algeria, we observed that the artisanal irrigation pivot we had studied as a local innovation in the Suf Valley had made its way to other settings.

This paper analyzes the diffusion of small artisanal irrigation pivots from its innovation

homeland, the Suf Valley, to other Saharan regions of Algeria and abroad. The aim of the study was to understand what adaptations were made to the artisanal pivot and to the innovation system that supported the diffusion of a local innovation and enabled it to travel. We identified the role of different innovation actors including artisans, smallholders, manufacturers, traders, government agents and other innovation intermediaries, in making the pivot work in areas hundreds or even thousands of km away from its homeland. This article contributes to the scientific debate on the importance of the creativity of local innovation actors in (supra) national agricultural development and food security in the Mediterranean.

2. Study area and approach

Study area

The Sahara Desert in Algeria covers an area of more than 2 million km², representing 80% of the national territory. In this very arid context – less than 200 mm/year of rainfall, and high evapotranspiration (2,000 mm/year) – groundwater represents an important resource on which economic and social development is based. In the Ghardaïa region, there is a longstanding ingenious artificial recharge system linked to an elaborate system to divert water from occasional flash floods (Saidani *et al.*, this issue). The Directorate of Water Resources (DRE) estimates an annual volume of nearly 186 Hm³ is extracted from the phreatic aquifer through 5 629 wells and 125 check dams. In addition, nearly 800 Hm³ are extracted annually through 680 boreholes, mainly from the Continental Intercalary (CI) aquifer, nearly 70% of which is used for agriculture, mainly in ‘modern’ agricultural extensions (DRE, 2018). The irrigated area of Ghardaïa department is over 34,000 ha (MADR, 2020). Our study area, the oasis of the Sebseb valley (one of 13 oases in the Ghardaïa department), was established on the bed of the wadi and is located 60 km south of Ghardaïa city (Figure 1).

In the past, the Sebseb valley was a caravan route, particularly between the south-east and the steppe regions of north-west Algeria. According to Caunneille (1968), the first palm trees were planted towards the end of the 18th century

by a few livestock breeders. During this period, the first irrigation wells, operated by human or animal traction, were built and connected to small channels (*seguias*) lined with plaster. Barley and wheat were grown on lands that were flooded through spate irrigation.

During the colonial period, the Sebseb oasis attracted farmers from Ghardaïa and Metlili, who were driven out by the successive droughts of 1923 and 1945 and the depletion of water tables in these oases (Dubief, 1953). This led to the introduction of groundnuts and apple trees in the 1950s and 1960s, that were associated in the typical three-layered oasis agriculture with the 2,000 existing palm trees in the gardens of Lehrith and Châbes El Argoub (Passager, 1958).

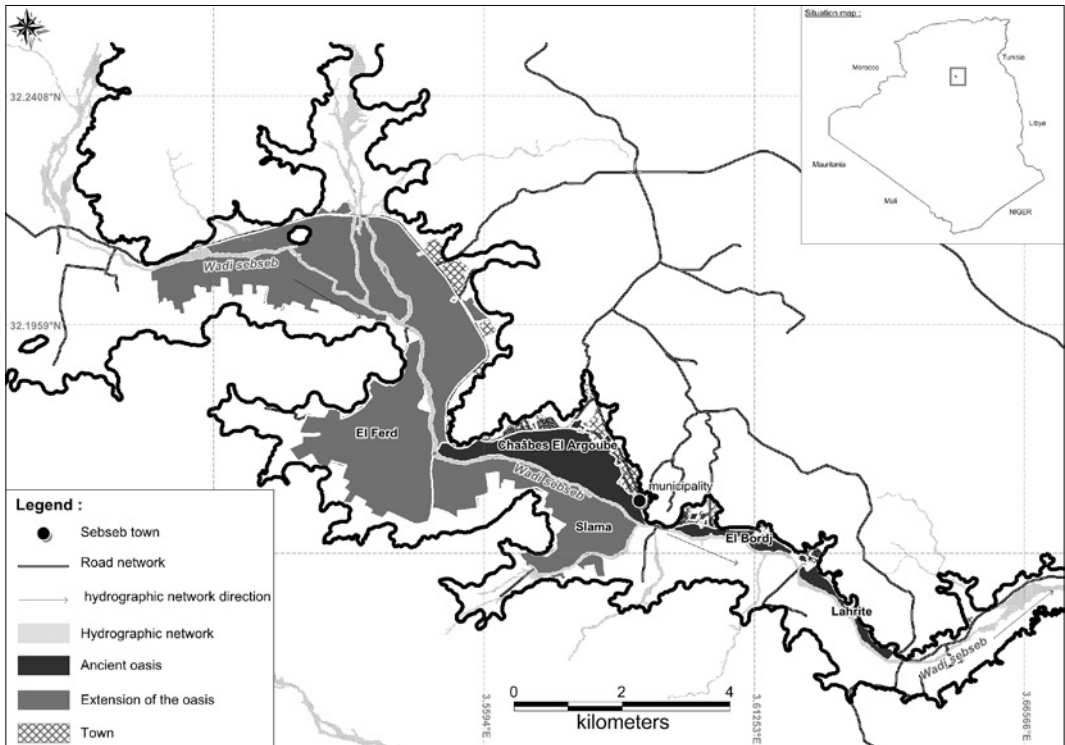
Today, the Sebseb valley covers an agricultural area of nearly 4,000 ha (DSA, 2020). The ancient oases are located in Lehrith and Châbes El Argoub, next to which extensions began in the early 1980s in the areas of El Ferd and El Djedid, and then from the year 2000 on, were extended to Slama and Boukhenfous (Figure 1). These extensions were carried out within the framework of the 1983 land law (APFA) outside existing oases.

Approach

We designed an approach to analyze the informal process of diffusion of the artisanal pivot to new areas of use. We first characterized the diffusion pattern of the artisanal pivot across the Sahara since 2000 through interviews with knowledgeable members of Suf Valley’s local innovation system, mainly manufacturers. We had already identified and met these actors in a previous study (Ould Rebai *et al.*, 2017). Based on these exploratory interviews, we selected the Sebseb Valley as our detailed case study, as the valley was mentioned as one of the main areas of diffusion of the pivot, with more than 250 artisanal pivots installed.

Second, we obtained information on how manufacturers, innovation intermediaries and farmers who use the pivots contributed to diffusion in semi-structured interviews. The cross-referencing of information enabled us to retrace the journey of the artisanal pivot and to identify the actors involved in the diffusion process. These actors were active only in the Suf Valley, or only

Figure 1 - Sebseb Valley, location and presentation of the oasis.



in the areas of diffusion, or in both. An innovation intermediary is usually defined as a person or institution that supports an innovation process, in this case the diffusion of the artisanal pivot, by providing information, knowledge, advice, or funds, or by acting as a mediator (Howells, 2006). We take this large perspective of innovation intermediaries (Klerkx and Leeuwis, 2009) by looking at the “bundle of links which unite the object to all of those which handle it” and their interests in the artisanal pivot (Akrich *et al.*, 2002, p. 205). Innovation intermediaries are (trusted) references for farmers in the study area, who consider them as their primary go-betweens with the two manufacturers who make and sell pivots in the Sebseb valley, thus making the link between the technology (manufacturer) and the market (potential users, artisans) and providing trust to this link, as the intermediary is known by both. These intermediaries benefit directly or indirectly from their intermediation (Akrich *et al.*, 2002), are known by most actors as having played this role, while developing attributes

(competence, knowledge, networks, credibility) that are part of the (in)direct benefits of having mediated and that may consolidate them in their role of intermediation.

These intermediaries are a trader, the only seller of the components of the artisanal pivots in Ghardaïa department, and four former farmers. We were able to track down the Sufi manufacturer in Sebseb through our first interview with one of the best-known and reputed manufacturers in Suf Valley. We obtained information about their experiences in disseminating the artisanal pivot outside Suf Valley, and through them got in contact with their intermediaries in different Saharan regions, and even outside Algeria. We conducted interviews with (i) an entrepreneur who was at the origin of the first travel of the pivot to Tamanrasset; (ii) an intermediary in Minea region, which the manufacturer considers to be his second important market after that of Suf Valley; and (iii) a trader in Algiers who was his point of contact with a Saudi firm and who assisted him in his first trip to Sudan. However,

this last person was quickly excluded from the pivot network and cannot be considered an innovation intermediary.

Subsequently in Sebseb Valley we identified and interviewed, in addition to 18 farmers using the pivot, three Sufi artisans related to the manufacturing and installation of the pivot, namely (i) a Sufi manufacturer who has been established in Sebseb since 2005; (ii) a manufacturer based in El Oued who has been selling pivots to Sebseb farmers since 2015; (iii) a Sufi artisan (turner) who supplies pivot components from Suf Valley to the sole seller of pivot components in Sebseb. The latter was also interviewed. We also identified and interviewed a farmer from Suf Valley, who acted as an intermediary to the manufacturer of Suf Valley, and another farmer (considered a leader in Sebseb Valley) who was instrumental in making the work of the Sufi manufacturer in Sebseb known.

The interviews revolved around three main topics: (i) their role and involvement in the innovation system of Suf Valley and their interactions with the various actors in the new settings; (ii) the technical adaptation of the pivot to new contexts of use; and (iii) the difficulties encountered in its diffusion.

This was completed, third, by field observations, in workshops and 18 farms, of the fabrication and use of pivots in Sebseb Valley and of the adaptations made to the pivots in the new areas of use.

Fourth, interviews were conducted with resource persons who were selected because of their familiarity with our study area: the president of the agricultural chamber, the agricultural delegate of the local administration, and executives from the Directorates of Agriculture and Water Resources. These interviews covered two main aspects: the introduction of the artisanal pivot in the Sebseb valley (areas of use of the artisanal pivot and the estimated number of pivots in use) as well as the biophysical and sociotechnical context of the study area and its farming systems.

We conducted 27 semi-structured interviews between October 2020 and May 2021: 18 farmers, one trader, 4 artisans (3 of whom live in Suf Valley and 1 in Sebseb) and 4 resource persons. Our first interview was with a pioneer inventor of the pivot concerning his experience in diffusing the artisanal pivot outside Suf Valley. This first contact enabled us to locate a manufacturer who had

moved from Suf Valley to Sebseb Valley, with the help of a metal worker in his neighborhood and then with the help of his first customer in Sebseb. Building a relationship with interviewees based on trust is important in the cultural context of the Sahara, especially where business is concerned, and the main author had to be introduced progressively to the different interviewees. Our first interviews with artisans and intermediaries enabled us to trace the diffusion pattern of the pivot in Sebseb Valley and to identify the two manufacturers operating on this market. Along the way, we discovered imitations and pivots made by other manufacturers on an emerging market, and we included these experiences in our survey.

Sample farmers were chosen from among the users of the pivot and we made interviews and observations to understand (i) the dynamics of the network of actors linked to the pivot: the length of time the pivot had been in use and the adaptations made to the device once it was installed, the user's relationship with the manufacturers, the intermediaries as well as the innovation network of Suf Valley; (ii) the use of the pivot on the farm, in particular the number of pivots installed, the cropping systems and ratio of the total area irrigated with the pivot to that of other parts of the farm; and (iii) the degree of competition between manufacturers and their strategies aimed at dominating the market.

3. Results

3.1. Journey of the artisanal pivot outside its innovation homeland: the role of manufacturers, local intermediaries and farmers

The very first pivot travelled from the Suf Valley in the year 2000 to Tamanrasset, more than 1 000 km south (Figure 2). A Sufi public works entrepreneur working and living in Tamanrasset, talked to many entrepreneurs and farmers about the success of the artisanal pivot in the Suf Valley. Proud of this success story, he particularly underlined the suitability of the pivot for irrigating small areas and the possibility to grow potatoes, its relatively low price, the after-sales service provided by the manufacturers, and its ease of use. He even thought about further possibilities for exporting the pivot: "Tamanrasset

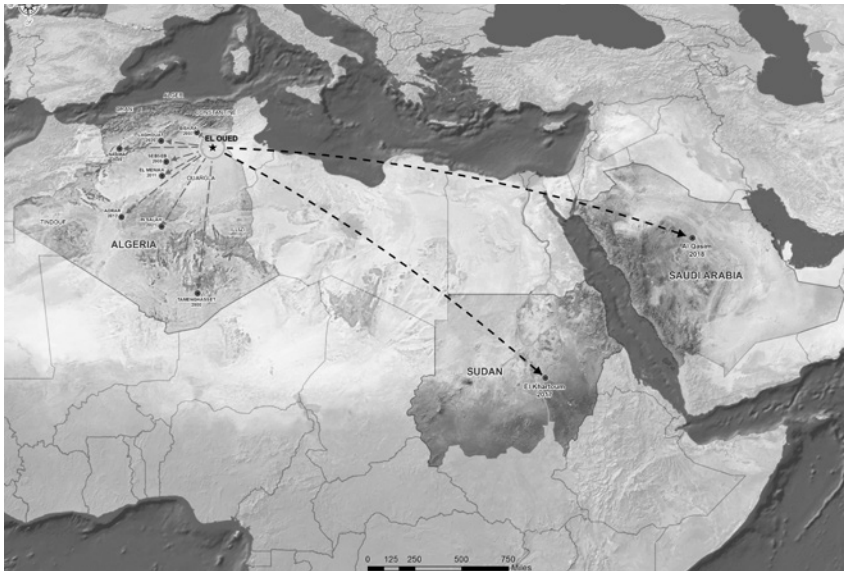


Figure 2 - Journey of the artisanal pivot outside its innovation homeland.

is a border region like Suf, the particularity is that the Tuareg in this region are in contact with Malians and Nigeriens. My wish was to make our creativity cross borders!” (Innovation intermediary in Tamanrasset, 70 years old). This intermediary then helped a farmer in Tamanrasset to get in touch with one of the manufacturers (here named Rashid¹) to order and install a 50-m pivot. This intermediary has continued to refer other farmers to Rashid. This was for example the case of two farmers from a neighboring department (Adrar) who came to see him twice after visiting the first customers in Tamanrasset. He also put in touch an artisan from Tamanrasset in 2010 with Rashid who travels or sends his workers to provide after-sales service. This intermediary thus remained involved in the network of the artisanal pivot by creating a link between the homeland of innovation (where he himself came from) and new territories (Tamanrasset, where he lived and Adrar). Such intermediaries generally have a direct link with the manufacturer (childhood friend, neighbor, family member, etc.) and intermediation in this case is often part of a broader social relationship and involves no direct financial benefits for the intermediary, who ensures, free of charge and to please the manufacturer, a proximity campaign

with local farmers. Yet, such exchanges kept this expatriated Sufi, proud of the achievements of his fellow Sufi’s, firmly linked to his homeland, reinforced his professional and personal networks, and provided social esteem.

However, for reasons of trust, intermediaries may also intensify their engagement in the network and become, for instance, a sales point for the manufacturer and identify new customers, a service for which they are paid. This was the case in the Menia area, where the intermediary we interviewed receives a total of 10,000 DA per pivot for his work: 50% paid by the customer (amounting to 3% of the price of the pivot), but he also receives 5,000 DA from the manufacturer once the sale is completed. For Rashid, this area is his second market after Suf Valley, and 65 pivots had been sold there at the time of writing (Figure 2).

The timing of the first journey of the artisanal pivot (to Tamanrasset in 2000) coincided with (1) stabilization of the design of the pivot, i.e., some major technical improvements had been made, in particular solving problems of poor anchoring of the steel wire and the wrong rotation cycle due to an unsuitable timer. Some remarkable breakthroughs were made, for instance, local artisans produced a gear reducer motor using

¹ The names are fictitious to ensure the anonymity of our interviewees.

recycled parts collected from scrap metal shops, and succeeded in establishing the correct speed for the pivot; (2) the maturity of the supporting innovation system was achieved when support services for the sale, installation and repair of pivots had been established, and (3) the beginning of its massive diffusion in the Suf Valley, five years after the start of the process of the re-design and improvement of the pivot through an open and collective incremental process of innovation (Ould Rebai *et al.*, 2017).

After this first journey, the pivot was sold and installed in other Saharan regions in Algeria, including Biskra, Adrar, Naâma, Ain Salah and Sebseb, our study area (Figure 2). Three groups of actors were instrumental in the journey of the artisanal pivot from Suf Valley to Sebseb Valley and its diffusion in the study area from 2004 on: (i) two manufacturers, who are active in the study area, built the pivot in their workshops in Suf Valley and Sebseb Valley, respectively; (ii) innovation intermediaries contribute actively to the diffusion process and are particularly important for the networks they have in the Sebseb Valley; and (iii) farmers usually play a more general role in using and showcasing the innovation and in providing feedback to the manufacturers (sometimes via innovation intermediaries) about how the pivots function.

The first manufacturer, Saeed, native of the Suf valley, has lived in the Sebseb valley in Ghardaïa since 2006 when he moved there to sell pivots. Saeed made this choice because he had been unable to collect money owed to him by his customers in Suf Valley and consequently accumulated debts with his suppliers (hardware stores, artisans and traders). The opportunity to sell artisanal pivots outside Suf Valley came up thanks to a former neighbor, who worked as a farm worker in Sebseb: “My former neighbor, Saeed, was up to his neck in debt because his customers didn’t pay him what they owed! He needed a fresh start outside Suf Valley and I gave him the opportunity” (farm worker in Sebseb, a native of Suf Valley, 68 years old).

In 2004, following a sharecropping arrangement with a leading farmer in Sebseb, this worker encouraged the farmer to install a pivot. Gradually becoming an innovation intermediary, he

even took the farmer to visit the manufacturer (Saeed) in Suf Valley to see pivots up close operating in the field. The following year, the first pivot was installed on the farm of the leading farmer, which had a real showroom effect and led to orders from neighboring farmers. Saeed subsequently settled in Sebseb and monopolized the supply, i.e., he handmade and installed more than 250 pivots. Fifteen out of the 18 farmers in the sample are his customers. However, even after having settled in Sebseb, he continued to rely on his innovation intermediary. As a farm worker, this intermediary had two specific qualities that made him indispensable once he had helped to make the first deals. He had a good operational knowledge of the pivot as he had used it himself on the pioneer farm in Sebseb. His practical experience gave him credibility and drew him close with to farmers, providing further opportunities to prospect and develop new markets. Interestingly, despite settling in Sebseb, Saeed also stayed in close contact with the innovation system in Suf Valley to keep up to date on the ever-evolving innovation.

The second manufacturer, Rashid, one of the first innovators of the artisanal pivot, chose to remain in Suf Valley, despite all the external market opportunities. Rashid justified his choice by (i) the size of the local market in Suf Valley and his success in selling pivots there (unlike Saeed), Rashid sold an average of 80 to 120 pivots per year, (ii) the fact that Suf Valley is the national reference and customers from elsewhere generally come here for advice and purchase, and (iii) the very active innovation system in Suf Valley, which continually improves the functioning of the pivot, originally only for local farmers but increasingly also for the areas where the pivot has traveled. In other words, the innovation system in Suf Valley remains active at a local scale with ongoing adaptations to the pivot and has gradually extended its reach to other areas in the Sahara, thus making it attractive for a manufacturer to remain there. In the process, there has been a change in the main function of the innovation system as it now caters to a wider range of users; new innovation intermediaries are included, aware of the particularities of a given territory; and the technology is also adapted (see 3.2).

In many cases, the first contacts between intermediaries representing potential future users and innovation actors in the Suf Valley do not directly involve the manufacturers, because intermediaries in other areas prefer to get in touch with the people in Suf Valley who are members of their (trusted) social network. These intermediaries may be entrepreneurs, transporters, traders or farmers. They may or may not originate from the innovation homeland. A known and trusted farmer who uses artisanal pivots in Suf Valley is generally the first local contact to get in touch with a manufacturer. Using a series of intermediaries is often necessary for both the manufacturer and a customer located in another area, particularly in the first year. This is a guarantee of trust for them, especially as these are informal relationships. These intermediaries play a vital role and it is thanks to them that the pivot has travelled to many areas in the Algerian Sahara.

The number of intermediaries may increase even more, especially when it comes to distributing to a foreign country. In this case, the social media may play an important role in enabling different intermediaries, the potential client, and the manufacturer, to communicate at a distance. This is illustrated by the experience of the manufacturer Rashid who exported a dozen pivots to Sudan and Saudi Arabia. A YouTube video posted by Rashid in 2017 attracted the attention of the director of a Saudi firm that had invested in the production and sale of forage crops grown under large pivots in Sudan and Saudi Arabia. To reach the Raschid, the new client went through a first point of contact, a trader in Algiers, who was known to him. Passing through a nearby hardware store (owned by someone who originally came from Suf Valley) this trader got in touch with Rashid, the manufacturer, through a farmer in Suf Valley, who knew the person from the hardware store. The trader then asked the manufacturer (Rashid) to travel to Sudan and Saudi Arabia to manufacture and install pivots. However, the Sufi manufacturer, Rashid, wanted to eliminate the intermediary (the trader) from his dealings with his future foreign clients. Therefore, using WhatsApp and Facebook, Rashid contacted the director of the Saudi firm: "As soon as the Saudi firm got in touch with Rashid,

to avoid being in an awkward position with him, this firm rewarded me for my efforts" (the trader, innovation intermediary with the Saudi firm, 45 years old).

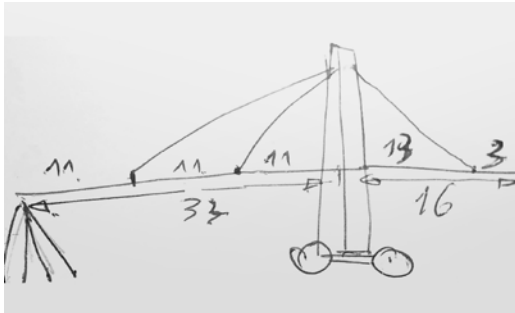
After more than three months of contact, Rashid travelled abroad, thereby allowing the pivot to travel to other African countries and to Asia. Before travelling, Rashid, the manufacturer, laid down a few conditions, in particular (i) His travel expenses (payment of transport, accommodation and catering costs) were paid by the client, the Saudi firm (ii) Rashid would not have to reward the intermediary, who was thus excluded from the sociotechnical network of the pivot; and (iii) the Saudi firm would put 3 workers at his disposal to adapt the pivots according to their needs (100 m long covering more than 3 ha of fodder crops, provide for adequate adjustment with the industrial motor gears). This means that the diffusion of innovation in this case concerns both the artefact, which is adapted to the new needs, and also the know-how, given that the workers on the farm will acquire new skills in the manufacture of the artisanal pivot.

3.2. Staying involved in the Suf Valley innovation network to adapt the artisanal pivot to a new context

Here we show how the diffusion of the artisanal pivot in the Sebseb valley was accompanied by ongoing adaptation of the pivot to its socio-economic, agrarian, and biophysical context. This adaptation was possible because the manufacturers remain firmly rooted in their innovation homeland and actively participate in its socio-technical network, interacting with other manufacturers and different artisans, traders, and farmers.

The first attempt to imitate and manufacture the artisanal pivot in 2000 is a good illustration of this process. Following a visit to Suf Valley, Djafar, a young farmer from Sebseb manufactured and installed a copy of the artisanal pivot on his father's farm. The pivot was 35 m long, based on the available surface area but adjusted according to the most common model in the innovation homeland, which is a 50 m long. The faulty location of the three rings that fix the wire on the crossbeam caused the problematic

Figure 3 - A sketch drawn by a seller of accessories of artisanal pivots in the Sebseb Valley, who aimed to manufacture a pivot whenever the opportunity arose.



distribution of the weight of the crossbeam on both sides of the tower (Figure 3). This incorrect adjustment made the 35 m pivot unstable. The Sufi manufacturer told Djafar that this required a readjustment of the device. However, despite repeated requests, he never came to help. This led the young farmer, Djafar, to abandon his project: “I then learned that the first pivot made by one of the pioneer manufacturers was 36 m long and not 50 m, but I don’t regret having tried!” (Djafar, farmer, 47 years old).

This attempt at imitation by the young farmer aimed at intensifying farming systems and gaining a place on the new market for pivots, but it failed. However, it led to the first change in the design of the pivot, i.e., adjusting its length according to the needs of the farmers, in particular the available surface area and the cropping system. Saeed, the manufacturer who has lived in Sebseb since 2006, manufactured 35-m pivots for some farmers in the old oasis of El Lehrith over a period of two years. Faced with multiple requests from farmers, he then adapted the 50-m pivot to their needs by readjusting the location of the attachment brackets on the crossbar, to which the pulling cable is fixed. This allowed the farmers to change the length of the pivot by a simple assembly and disassembly of a ladder without the pivot becoming unstable.

The need for such an adaptation is explained by the particularity of the farming systems in Sebseb. In Suf Valley, the artisanal pivot is mainly used for monoculture (early and full season potato) with pivots covering 60-100% of the total area of the farm (Ould Rebai, 2019). In the

Figure 4 - PVC pipe leading water under the pivot, a local DIY adjustment to avoid corrosion caused by saline irrigation water.



Sebseb Valley, however, small-scale peasant systems are dominated by mixed cropping systems. Thirteen out of the 18 farmers in our sample own 2-5 ha and the other 5 farmers own between 5-10 ha. All farmers engage in arboriculture on 1-2 ha (date palms or citrus trees with barley or peanuts as intercropping). On these farms, the pivot generally irrigates 30-50% of the total agricultural area. All farmers practice crop rotation, and two main cropping systems were observed under the pivot (a) groundnut-barley rotation (5 farmers out of 18); and (b) carrot-barley-fallow (13 farmers out of 18).

The artisanal pivot also needed adapting to cope with corrosion due to the saline water in wells in the Sebseb Valley (Houichiti, 2009). The first farmer, who installed a pivot in Sebseb Valley, was inspired by the idea of flexible sheaths used for the same reason in Suf Valley which allow water to be brought under the pivot to avoid corrosion: “The Sufis have interesting ideas that inspire us to adjust our pivots to our means and needs” (farmer, 63 years old).

The farmer in Sebseb had the idea of replacing the ramp of the crossbar by a PVC tube, 60 mm in diameter, along with PVC pipes 25-mm in diameter, mounted together in the form of an elbow directed downwards (Figure 4). The sprinklers are then placed on these PVC elbows and the steel crossbar serves as a support linking the whole device with the tower. 11 farmers out of 18 have adopted this innovation.

In addition, faced with the lowering of the water table, seven farmers decided to deepen their wells to 50 m or even 110 m and to replace the

motor pump units with immersed pumps. The aim was to increase pumping pressure to achieving good rainfall coverage by the pivot. The practice of converting wells in Sebseb Valley began in 2017 and is becoming more widespread, because the aquifer used by the farmers is no longer fed by wadi Sebseb due to a prolonged drought. We also observed two farmers, who did not have enough means to deepen their wells, who replaced their sprinkler with other types they considered to be more water efficient i.e. less flow and a lower operating pressure.

A second attempt to imitate the pivot was made in 2020, twenty years after the first, by the only trader of accessories for artisanal pivots in Sebseb, who interacts with artisans and traders in the innovation homeland. Due to the unavailability of Saeed, one farmer who wanted to contact a manufacturer in Suf Valley to order a pivot and to sow peanuts in time to not miss the season turned to this trader for a contact. The trader took advantage of the opportunity and promised him a pivot in one week at a lower price. By calling on two welders in his neighborhood, the trader built the pivot using the design that he had drawn the previous year after discussions with artisans of Suf Valley (Figure 3). To make the pivot lighter and to increase its speed of movement, he reduced the size of the tower and used welded wire mesh instead of angle steel at the pivot crosspiece. However, due to poor fixation and destabilization of the device, the attempt failed.

The different attempts to adapt the pivot to the prevailing conditions in the study area described in this section, yield several lessons. First, when the adaptations were embedded in the extended innovation system of Suf Valley, combining the expertise and skills of Suf Valley artisans with user experiences in other settings, the necessary modifications could be made rapidly. Conversely, the attempts to acquire manufacturing skills by novices in the new areas, who tried to become independent of the innovation homeland, generally failed. However, in some cases these attempts inspired adaptations by manufacturers in Suf Valley that eventually succeeded. Second, the pivot was substantially adapted to fit the new context, for example by manufacturing pivots whose length could be adjusted (35-50 m) or by adapting the

sprinkler system to avoid corrosion. This case is a clear example of the multiple links that were created between actors in Sebseb and Suf valleys, challenging the manufacturers in the innovation homeland to adapt the pivot to new conditions.

3.3. Closing an open innovation to maintain a monopoly in new agricultural areas

We now analyze the strategies of Suf Valley manufacturers to secure their monopoly on the new markets, which is contrary to the open innovation environment that characterizes Suf Valley, of which they are also part. Indeed, in Suf Valley the pivot was gradually developed as an incremental innovation with inputs from many different artisans who shared responsibilities in the design process (Ould Rebai *et al.*, 2017). No single manufacturer can claim intellectual property of the pivot, and it is precisely by opening up processes of design and diffusion while engaging in a continuous dialogue with users that the pivot came about.

Conversely, in Sebseb Valley, the Sufi manufacturers strived hard to close this innovation to outsiders using different strategies. The first strategy was linked to their ambition to preserve Sufi intellectual ownership of specific components of the pivot. This was observed, for example, when Rashid, a Sufi manufacturer, installed pivots in large-scale farms in Sudan and Saudi Arabia. The Saudi firm wanted Rashid to mount the artisanal speed reducer on-site and put a metal worker at his disposal, as the alternative industrial geared motor model imported from China was more expensive. However, Rashid did not agree, as he considered the speed reducer was not his personal property. It belonged to the innovation homeland and represented, for the Sufi artisans, the black box of the artisanal pivot that should not be opened.

Similarly, the Sufi manufacturer installed in Sebseb (Saeed) avoided involving his workers in the manufacture of this component, he only did it at night after closing his premises. However, a seller of pivot components in Sebseb circumvented the monopoly by ordering speed reducers directly from metal workers in Suf Valley, which prompted this manufacturer to stop producing them.

The second strategy of manufacturers concerns the provision of well-developed after-sales service. This helps to develop close relations with customers by monitoring and checking the new pivots installed. Rashid used this strategy when on returning from Sudan in 2017, he noticed that orders in the department of El Minea had dropped significantly (2 instead of 8-10 pivots sold per year). After investigating the reasons for the decline in orders, he discovered that many breakdowns had occurred due to sub-standard installations by his employee. In his absence, this worker had not come to make the repairs despite repeated requests from the intermediary. The latter admitted that he was put in an embarrassing situation, as this complicated the trust farmers had in him, diminishing his credibility. Farmers knew that he benefited from the business (3% from the selling price from the manufacturer and 3% from the farmer), and now he did not deliver. As a result, farmers turned to a new competing manufacturer in Adrar.

Faced with this loss of market share and on the advice of his innovation intermediary, the manufacturer decided in 2018 to dedicate about ten days each year to a field tour: "After the manufacturer returned from Sudan, I recommended he should come and personally reassure the new customers I found for him, I needed his promise in front of them!" (innovation intermediary in Minea, 43 years old). The tour is scheduled with customers through direct contact or through the intermediaries when Rashid has sales points in the area. This is done to anticipate problems and prepare for repairs. The trip is generally scheduled during the potato harvest season in Suf Valley (mid-December to the end of January), which is the least busy period for manufacturers in Suf Valley with few orders, installations and repairs.

This shows once again that the diffusion of an innovation cannot be limited to the (black-boxed) artefact and that the know-how of (here) manufacturers is crucial. Despite having a good reputation, a manufacturer must remain vigilant and continually satisfy the demands of the market, especially as competition for the diffusion of the artisanal pivot outside its homeland is increasing. The importance of continuously responding to market demand is also demonstrated by Saeed's experience. In 2015, when a farmer

was angry that his orders were not taken into account, he looked for a manufacturer who would provide after sales service to local farmers. The farmer managed to locate one, named Fateh, through his brother-in-law, a transporter who is in contact with farmers in Suf Valley. Fateh is a former manufacturer who is quite well known in the area of innovation and who has already sold pivots outside Suf Valley, in particular in Biskra administrative department. His new customer in Sebseb Valley ordered and installed two pivots from Fateh but also filmed and published videos on the Sebseb municipality's Facebook page, recommending Fateh's pivots to his neighbors.

The third strategy is offering customers a range of choices depending on the quality of the materials used to make the pivot (i) a *top quality pivot* model costing 190,000 DA (1368 US\$) (transport from Suf Valley and assembly included) comprising a galvanized tube crosspiece, which is lighter and more resistant to corrosion and rusting than steel, a new speed reducer and new, good quality wheels and tires; (ii) a *2nd choice pivot* model at 160,000 DA (1152 US\$) (including transport from Suf Valley and assembly): made of a steel crossbar, a speed reducer, but wheels and tires recycled from an old pivot.

We identified a fourth strategy in response to increasing competition in the market for artisanal pivots. So far, Fatah has sold and installed almost 50 pivots in Sebseb Valley, 20% of the number of pivots sold by Saeed. For this reason, Saeed has changed his policy concerning credit and after-sales services. Following his negative experience of selling on credit in Suf Valley in the past 15 years, Saeed offered no credit in Sebseb Valley, with 10% down payment when the order was placed, the remainder to be paid on the day of installation. However, his new strategy consists of (i) limiting after-sales service (i.e. assembly and installation, repairs and maintenance as well as advice and adaptation) to his own customers; (ii) giving financial advantages to good customers by selling on credit, 70% in advance and 30% afterwards, discounts of 5,000-1,000 DA, and fills their orders first, etc. These good customers represent 4 farmers (out of 18) of our sample, as they own more than 4 pivots each and convince other farmers to order pivots from him.

4. Discussion and conclusion

In this paper, we analyzed the diffusion of a local innovation, an artisanal small-scale low-cost center pivot. Developed initially by a dense innovation system in Suf Valley to cater for the specific needs of farmers in the area, we were interested in how it travelled elsewhere in the Algerian Sahara and beyond. What adaptations to the pivot were needed to allow this journey to take place and how was the innovation system reconfigured and extended to support this journey? Three sets of factors are of interest to answer these questions: 1) the attributes of the innovation (the pros and cons of the artisanal pivot that was progressively adapted); 2) the characteristics of the adopters and their involvement in adapting the pivot; and 3) the “salience of issues related to the innovation”, i.e., the importance and relevance of the pivot for potential users and innovation intermediaries (Dearing and Cox, 2018).

We showed, first, that the journey of the artisanal pivot outside its homeland operated through the same innovation system involved in the production, use and diffusion of the pivot in Suf Valley. What travels initially is the idea of the artisanal pivot through the (enthusiastic) descriptions of people originating from Suf Valley, proud of their innovative homeland, to their new neighbors. This is sometimes substantiated by a visit to a manufacturer in Suf Valley. What travels next is the artefact, as designed for Suf Valley, which is installed on a farmer’s plot in the new territories, leading in all cases to technical difficulties. This leads in turn to the travel of knowledge and know-how from Suf Valley as the pivot needs to be adapted and its use continuously supported. Artisans either establish themselves in the new areas or they go on technical missions from their home base. So, what travels in fine is the socio-technical system, that is the artefact, embedded in an innovation system. In particular the manufacturers are main players in the diffusion of the pivot in new settings. They know the attributes of the pivot perfectly well and their strong point is that they are able to modify these attributes, for example by changing the size of the pivot. To do so, they call on their network of artisans and traders, who, in

turn have the necessary skills and networks to obtain the components they require. The innovation system in the homeland can therefore be considered as a crucial back-up system to the first main factor influencing diffusion. However, these key players cannot deal with all the main factors that influence diffusion, and the innovation system also needs to be reconfigured.

To this end, second, the manufacturers looked actively for innovation intermediaries and intermediaries also often got in touch with manufacturers themselves. These intermediaries come from different backgrounds and had different profiles (farmers, workers, traders, transporters, entrepreneurs), they may or may not originate from the innovation homeland and are in direct or indirect contact with the manufacturers. Their engagement in the sociotechnical network was beneficial to them, but also led to changes in the network and in the technology. These findings are in line with those of Benouniche *et al.* (2016, p. 76) who showed how a variety of non-conventional actors progressively joined innovation systems as innovation intermediaries, and how their “commitment induced reciprocal changes in the technology and in their socio-professional status”. However, our results showed – just like those of Benouniche *et al.* (2016) – that not everybody joining the sociotechnical network as an intermediary is successful or interested to remain. For example, the entrepreneur who had facilitated the first contacts with customers in Sudan and Saudi Arabia was rapidly excluded from the network due to a lack of legitimacy and added value of his intermediation beyond the initial contact.

One of the first tasks of intermediaries is to help manufacturers in characterizing farmers and the farming systems in the new areas, and hence potential adopters of the pivots. The initial intermediaries generally contacted farmer leaders who became the first customers of the pivot. Because of their strong sociability in their territories, these leading farmers helped Sufi manufacturers to develop new markets, in particular through the showroom effect of the first pivot installed, thus becoming innovation intermediaries themselves. Ideas of adapting the device to the context of use of these areas were also contributed by neighbors and fellow farmers and were

then passed on to the manufacturers as feedback. Traders too play an important role as innovation intermediaries: they guarantee the availability of pivot components to farmers and also give them advice (Daoudi and Lejars, 2016). The traders sometimes attempt to manufacture and install pivots themselves to gain a place on the market. Finally, open innovation processes are facilitated by the expansion of information and communications technologies that enable users to share ideas and comments and evaluate the use of innovations (Martínez-Torres, 2014). In our case, social networks were used to facilitate exchanges and enable the journey of the pivot to places as far away as Sudan and Saudi Arabia.

Making the pivot important and relevant for users in the new areas was hard work. The pivot had to be adapted to new farming systems and to particular biophysical and socioeconomic conditions, while the innovation system had to combine the experience and skills of Suf Valley artisans with the active involvement of farmers and intermediaries in redesigning the pivot and the supporting innovation system (to design, sell, install, maintain and repair the pivots). Perhaps the hardest task was to find the right users for whom the pivot is both important and appropriate, which subsequently encourages them to become actively involved in the innovation system.

Third, the journey of the artisanal pivot is characterized by manufacturers' strategies of locking in the pivot to secure intellectual property and maintain monopoly in new markets. This closure of the innovation is in apparent contradiction to the open innovation context in the innovation homeland. However, it is in agreement with the analysis conducted by Perry-Smith and Mannucci (2017) on the facilitating role of closure of innovation along the process of diffusion, notably to reduce uncertainty for manufacturers. Indeed, Sufi artisans consider that the essential components of the artisanal pivot are the common property of the local (Sufi) innovation network. This shows a fascinating articulation between the open innovation environment in the innovation homeland, where intellectual property is shared and no monopoly is permitted, and the closed environment in its new settings. Potential competitors there are thus excluded from Sufi

know-how. However, we also showed that the open innovation environment in the homeland enabled customers in the new areas to find alternative manufacturers, almost always in Suf Valley, willing to sell them the pivot and provide after-sale services, thus avoiding a monopoly.

In conclusion, the analysis of the trajectory of the artisanal pivot journey, outside its innovation homeland, shows how an innovation network that produced, used, and diffused a successful but local innovation, was able to make it travel and adapt it to new settings. The creativity of local innovation actors can, therefore, contribute to broader processes of societal change and to issues like food security. Research, administration, and extension services should, therefore, support and accompany changes by taking part in local innovation processes.

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