Frugal Innovation for Inclusive Development: A Case Study on Power Tillers in Tanzania

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1. Introduction

The Leiden-Delft-Erasmus (LDE) consortium, in collaboration with REPOA, has developed a research project aiming to understand the role of innovation, technology transfer, and technology networks in Africa's economic transformation. This role is articulated via the notion of frugal innovation. In its literal meaning, the term frugal is related to scarcity of resources, be it financial, technical capability, or institutional. The application of this notion in this project is along the same broad lines. Frugal innovation is viewed as a process of transforming a product's technical complexities while retaining their basic functionality. This process is mainly targeted at reducing product costs or making them adaptive to operating conditions of marginal populations or relatively poorer consumers. Frugal innovation, or frugal engineering as is sometimes referred to, can apply to any product or service. For example, General Electric Company developed a hand-held electrocardiogram (ECG), which reduced ECG tests to about one dollar per patient (The Economist, 2012). Important considerations in understanding the process of frugal innovation include both technological dimensions and institutional dimensions, which together affect the process of technology (or products and services) transfer, adaptation, and its social and economic impacts. Thus, it concerns value-sensitive design and marketing strategies that bring sophisticated products within the reach of relatively poor consumers, referred to in this project as the Bottom of the Pyramid (BoP).

The majority of the BoP live in Africa and mainly in rural areas. In Tanzania, for example, where more than 74% of the labour force is engaged in agriculture, poverty is quite pervasive, especially in rural areas. According to the Household Budget Survey of 2012, 33% of rural households live below the poverty line (United Republic of Tanzania, 2013). Since the majority of rural households are predominantly smallholders engaged in labour intensive agriculture, designing interventions for improving productivity is considered critical if earnings are to be raised and poverty reduced. One important element to address in this respect is production technology, which includes mechanization of farming activities. It is no wonder therefore that the project's pilot phase elected to focus on introducing and utilizing power tillers among smallholders, with particular reference to Tanzania, despite the fact that frugal innovation is applicable to many other types of products.

From the early years of experimentation in Tanzania, power tillers were viewed as an appropriate technology for most smallholder farmers. The use of power tillers was accelerated following the announcement of the "Kilimo Kwanza" initiative, meaning "Agriculture First", in 2009. This case study provides an analysis of the institutional processes underlying their introduction and adoption, and the design features reflecting the suitability of the power tiller innovation in relation to their expected contribution.

This report is organized as follows. Section two discusses the study's objectives, underlying hypothesis, and research questions. The applied methodology is discussed in section three, while section four presents the findings. Section five discusses the study's overall contribution to the research theme on frugal innovation, and section six contains the conclusions.

2. Research objectives, hypothesis, and research questions

The research programme on frugal innovation is intended to inquire about the conditions under which frugal innovations are more likely to stimulate development in the African context. While there is a general consensus that frugal innovation can be beneficial to businesses and the poor, there is a knowledge gap on what really can be considered frugal innovation/engineering, its institutional processes, and how and when the benefits can accrue to firms and the majority of those in the BoP, or the majority of the people in sub-Saharan Africa (SSA).

This kind of research involves analyses of consumer preferences and how re-engineered products suit their needs or otherwise in terms of the design features, and the process by which the products are introduced, marketed, and institutionalized. The process of reengineering and the institutional process are not necessarily mutually exclusive, and are often interlinked if the innovation process is to translate into a viable business model. The objective of this case study is to provide a brief analysis of frugal innovation in the introduction of small, hand-operated tractors, commonly known as power tillers, as a solution to low output and productivity of smallholder farmers. It will focus on innovation in terms of the product's key design features and the institutional platform underlying it, and the results it has generated. The study is anchored on the broader

hypothesis of the research programme, that is, locally **embedded knowledge and technology networks are important elements in successfully re-engineering high-value products for low-value but high-volume markets.** The interpretation here is that while some manufacturing firms have moved into more modern and sophisticated agricultural machines, they have at the same time re-engineered those products and technologies to produce simpler and cheaper machines that are affordable and applicable by low-income and unsophisticated smallholders.

The operationalization of this hypothesis is as follows: **the introduction of power tillers as means to help smallholders improve their output and productivity has not succeeded because of both limitations on technical design and neglect of institutional dimensions.** The technical design limitations relate to the efficacy of these machines under different soil types, terrain, and climatic conditions. The institutional dimensions relate more to the process by which the power tillers were introduced in Tanzania, mechanisms by which they reach the intended targets, and how they are utilized by recipients. Like any generic innovation, it is difficult for frugal innovation to occur under normal conditions, where firms and entrepreneurs take risks in new areas and where the target markets are those in the BoP, in the absence of institutional mechanisms to offset those risks. Some institutional actions, however, can also become counterproductive if the interests of various institutional actors are not aligned. Hence, understanding the broader institutional settings surrounding this particular frugal innovation and its outcome is as important as understanding its technical dimensions.

This hypothesis is explored by an attempt to answer the following research questions:

1. How were power tillers introduced and adopted by the smallholders in Tanzania?
2. What are the elements in the design of power tillers that make them suitable (or unsuitable) for smallholders under different agro-ecological conditions?

3. Research methodology

The first question led to exploring the institutional aspects of this innovation, including the processes by which this technology was evaluated and why it was considered relevant for Tanzania. The decision-making process and incentives of different actors in the process were investigated. Specifically, the following aspects were pursued:

a. The process of identifying technology and the decision to import vis-à-vis customization by local firms;
b. How the initiative was financed (role of government, private importing agent, local government authorities/district councils, farmer organizations, and individual farmers);
c. Institutional coordination through the chains – from acquisition to knowledge on power tiller maintenance and utilization.

To obtain relevant information for this kind of institutional analysis, interviews were carried out with key informants at different levels of government departments responsible for policy decisions and implementation and those from the private sector. These included the Ministry of Agriculture, Food Security and Cooperatives (MAFSC), National Service Business Unit (SUMA), the Ministry of Regional Administration and Local Government Authorities, selected district councils, and the importing agents and power tiller suppliers.

The second question focuses on examining key power tiller design features in relation to their intended functions. Thus, technical information was obtained from key suppliers where key design attributes were identified. These attributes were accounted for when examining the on-the-ground performance of key functions under different agro-ecological conditions. Semi-structured interviews (Appendix 1) were held with officials working in target districts and with farmers selected randomly in those districts. District selection was based on the distribution of the estimated 4,571 power tillers supplied in Tanzania, as shown in Table 3.1, where a significant number was supplied in six out of the 21 regions in Tanzania mainland.

Table 3.1: Distribution of power tillers by region

S/No	Region	No. of units	% of total
1	Mbeya	1073	23.47
2	Morogoro	327	7.15
3	Iringa	306	6.69
4	Shinyanga	246	5.38
5	Rukwa	242	5.29
6	Mtwara	217	4.75
7	All others	2160	47.25
Total		**4,571**	**100.00**

Source: Ministry of Agriculture Food and Cooperatives

While study robustness could have been improved by selecting a sample from all regions, budgetary limitations and time constraints made it prudent to select fewer areas. Two districts were selected from two regions with the highest number of power tillers, namely Mbeya and Morogoro. This selection was helpful because it increased the likelihood of reaching a high number of well-experienced farmers at reasonably low logistical costs. One district was selected from each of the two regions, based primarily on the same criterion, that is, a district with the largest number of power tillers. For Mbeya, this was fairly straightforward, as Mbarali district represented 97% of the region's 1073 power tillers. In Morogoro region, Ulanga, Kilosa, and Kilombero districts accounted for 27%, 23%, and 19% of the 327 power tillers in the region, respectively. However, farmers in Kilombero district engage in paddy production, just as farmers in Mbarali, but the difference in power tiller supply is significant. This led to the choice of Kilombero district.

The objective of the field survey in the districts was to obtain information relating to:

a. Key design parameters and how they relate to expected and current use;

b. Support mechanisms related to knowledge of use, maintenance, and operating costs;

c. How the power tillers have contributed to changing livelihoods of the smallholders – i.e. productivity increases, reduced transport costs, improved acreage under cultivation, increased income – or the reasons for a lack of change.

In Mbarali district respondents were drawn from two divisions, namely Rujewa and Ilongo. In Rujewa 45 farmers were interviewed, whereas only 15 farmers were interviewed in Ilongo. All respondents in Mbarali owned power tillers on the basis of individual ownership management. Table 3.2 shows the distribution of the sample in Mbarali.

Table 3.2: Respondents in Mbarali district

S/No	Division	Ward	Respondents
1	Rujewa	Madibira	30
		Mapogoro	15
2	Ilongo	Hambolelo	5
		Chimala	5
		Itambolelo	5
Total			**60**

Source: Survey data

In Kilombero district data were collected from 47 respondents owning power tillers. The respondents were drawn from three divisions, namely Ifakara (15 farmers), Mang'ula (16 farmers), and Mngeta (16 farmers), as shown in Table 3.3. Six respondents were farmers owning power tillers under farmer group management, whereas 41 respondents owned their power tillers under individual ownership management. The farmer groups have individual members ranging between 15 and 22 farmers each.

Table 3.3: Respondents in Kilombero district

S/No	Division	Ward	Respondents
1	Ifakara	Kibaoni	9
		Ifakara	5
		Lumemo	1
2	Mang'ula	Kiberege	2
		Mang'ula	7
		Kisawasawa	4
		Mwaya	3
3	Mngeta	Mngeta	16
Total			**4**7

Source: Survey data

4. Findings of the study

The study reveals a number of institutional and design aspects of power tillers hitherto unknown to the policy development fields or at least not documented in a systematic manner. Each of these findings is discussed in turn.

4.1 Institutional processes of product introduction: *Top-down, state-induced innovation*

Tractor mechanization for cultivation, farm transport, and processing took off in Tanzania since around the 1950s. Initially these tractors were used on foreign-owned estates growing tea, coffee, sisal, tobacco, and wheat. By the early 1960s the number of tractors rapidly increased to around 1600 units because of the emergence of a number of private commercial Tanzanian farmers with medium- to large-scale farms. The Tanzanian farmers used tractors mainly for production of maize in Iringa, wheat in Arusha, and cotton in Shinyanga, and by 1970 there were about 17,000 tractors (Kjaerby, 1986).

The evolution of hand hoe use in agriculture in East Asia in the 1960s was mainly driven by land tenure considerations. Due to the small sizes of farms, Japan and India invented small, hand-operated tractors initially designed for use in rice paddling, gradually replacing hand hoes. The focus of mechanization in Tanzania, however, was mainly on four-wheeled tractors. The modernization approach, adopted as part of the First Five Year Plan in 1964, aimed at opening up new areas for modern and mechanized farming, through supply of tractors and machinery. However, scheme implementation under this approach failed for various reasons, including the lack of sufficient preparation and overcapitalization relative to returns (Mmari, 2012). The reliance on manual power has continued to dominate agriculture in Tanzania and in other SAA countries (FAO, 2008). While the use of engine power increased by 500% between 1961 and 2000 in Asia, it increased by only 28% in SSA during the same period (ibid).

In Tanzania, partially due to the earlier tractor failure, the Second Five Year Plan from 1969 stressed the use of draft animals instead of tractors in an effort to transform farming from manual or human-power dependency to animal power, with

the establishment of an animal breeding centre in Mwanza region for producing bulls that could endure longer working hours and produce greater power. Animal power, however, was confined to pockets around the country and became insufficient as the population grew and the area under cultivation increased. Although the use of tractors continued to expand on the large-scale state-owned farms, on the whole the population of tractors decreased from 17,000 units in 1970 to less than 6,000 in 1990s due to a variety of reasons (FAO, 1997).

Experimentation with alternative forms of mechanization started in 1965 via a hand-operated garden tractor imported from the Netherlands for training purposes, but no additional efforts were made to introduce the technology into farmers' fields. The first trial runs were initiated in the 1990s, when ten power tillers were acquired from Japan by the Mechanization Department of the Ministry of Agriculture, under the Food Security for the Underprivileged Farmers project, commonly known as the "2KR" project. The ministry's staff had to rely on the user's manual as they had no formal training. The trials and promotional activities were first undertaken in Morogoro region, which led to the request for twenty additional power tillers from Japan. This marked the beginning of the use of power tillers in Tanzania, albeit at a very small scale. The ministry sold these power tillers at a subsidized price equivalent to two-thirds the CIF value in Dar es Salaam.

In 2002, the Ministry of Agriculture targeted additional districts for power tiller promotion, including Mbarali district. More power tillers were requested, for which 120 units were delivered under the same project. The ministry required all regions to indicate their need for power tillers, but the response was very low. Subsequently, the ministry decided to allocate six units to each region, and then organized a heavy campaign to promote power tillers in the regions, working with regional leaders and local government authorities. Mbarali district responded well. The agricultural training institute located in Igurusi village in Mbarali took up the challenge to support farmers, particularly for setting up irrigation schemes for rice production. The institute offers diploma programmes in irrigation and land use planning. The initiation of these irrigation schemes sparked the demand for power tillers in Mbarali district, which partly explains the prevalence in their use there compared to other districts.

The increase in the number of power tillers in many other districts came in the wake of a 2010 directive from the Prime Minister to all district councils following the adoption of the Kilimo Kwanza initiative, where each district would procure 50 power tillers each year. In turn, the councils would distribute these machines to small-scale farmers and farmer groups. Under this arrangement, famers would contribute 20% of costs while councils, under the District Agricultural Development Plans (DADPs), would subsidize 80% of the cost. Many district councils responded, although most procured them in phases due to budgetary constraints.

Clearly, the supply of power tillers was driven by the government, although demand in Mbarali district was complimented by the introduction of irrigation farming schemes. The initiatives from the agriculture training institute at Igurusi were also a catalyst for the irrigation scheme development. As will be seen below, agro-ecological conditions and farming practices had an influence on differential demand. The decision to promote the use of power tillers country wide in the late 2000s, in the context of Kilimo Kwanza, did not take into account the technical characteristics of power tillers and the differences in agro-ecological conditions as determinants of their effectiveness. Political and administrative dexterity prevailed over technical considerations.

4.2 Response of private sector to changing demand for power tillers

Initial supply of power tillers by private traders was pioneered by Auto Sokoni Limited, operating in Dar es Salaam and other urban centres in Tanzania as an importer of various agricultural machinery. Auto Sokoni stocked a few power tiller units made by AMEC group of China, to whom they had been agents. Soon after the demand in Mbarali district surged, Auto Sokoni responded by importing more units and opening up supply branches in Mbeya and Iringa regions, from where they could serve rice farmers and others in the neighbouring districts.

More and more traders began importing power tillers from China, while others dealt with spare parts. At the same time, the parts supply for previous power tillers, ministry-supplied Kubotas from Japan, was running out. The coordinators of the

project had a previous agreement with International Motors, an agent of Toyota, to provide dealership for spare parts, but because the market segment was small relative to their main segment, they opted to pull out of the agreement. So, the supply of parts for Kubota machines became problematic. This problem made the Chinese-made machines more popular, because spare parts were readily available. New problems have, however, emerged in the supply of parts. As is the case for other types of machines, genuine parts are often more expensive than generic ones, making consumers prefer cheaper ones. Unaware of the significant quality differences, some power tiller owners have purchased cheaper, lower quality parts, resulting in frequent malfunctioning. In addition, many other power tiller brands have been introduced to the market, including those from India, Korea, and Thailand. For most smallholders who buy power tillers, the main driver behind the choice of type is the price, although the experience of current power tiller owners also dictates these choices.

4.3 Power tiller ownership by groups or individuals

There are three categories of power tiller owners: individuals who purchased these machines on their own from suppliers, individuals who benefited from the loan or the subsidy scheme, and farmer groups who acquired their machines through a subsidy scheme from the District Council. The first category was influenced more by needs arising from their agricultural activities, while the rest were more supply driven. As the data and the institutional process of introducing power tillers suggest, owners in Mbarali district acquired their machines mainly by purchasing them on their own or through their already established Savings and Credit Cooperative Societies (SACCOS). Survey data shows that the majority of power tillers in Kilombero district were acquired through support from the District Council, and so are owned by farmer groups, a condition preferred by the District Council as a way of reaching many farmers. Under this system, farmer groups pay 20% of the machine cost, while 80% is subsidized by the District Council. It has not been possible to establish directly whether ownership type matters for the outcome, although it appears that individual ownership is most likely influenced by owner demand rather than supply driven, and so individual ownership is more likely to be associated with more positive outcomes.

4.4 Embeddedness of local knowledge in product design and adaptation to local needs

Power tiller effectiveness is influenced in part by the design, but also by knowledge among those operating them. Conventionally, these machines are known as two-wheeled, hand-operated tractors. Three features determine their effectiveness. First is the ease of control, so that more engine power is used for tilling or any other intended use rather than for operation. Thus, a usable power-to-weight ratio is achieved when engines do not exceed 14 horsepower.

The second is convenience to the operator, such as the ease of reaching the controls, while the third is operator comfort. If conditions for the correct application of these machines are not met, it is likely to discourage their use or lead to modification by users and perhaps suboptimal use.

In terms of functions, power tillers derive their name essentially from engine-driven tilling, but tilling is just one component, albeit the main component. The rotovator, also known as rotary hoe, is the key implement that was designed for tilling light soils, applied for functional time and energy that human power could not produce. Other power tiller operations include ploughing, harrowing, ridging, and water pumping, but additional equipment has to be acquired for these purposes. Another operation, the only operation that provides a seat for the operator, is trailing.

Survey results reveal that all farmers in Kilombero and Mbarali districts own ploughs (disc/mouldboard). However, farmers in Kilombero also own trailers (93%), rotovators (80%), cage wheels (59%), and harrows (56%), whereas farmers in Mbarali district own cage wheels (92%), trailers (82%), and rotovators (72%). Water pumps and transplanters are not as common and would seem to play a minor role in agricultural production in both districts. Farmers and power tiller owners have made various modifications to suit some local needs – i.e. locally driven re-engineering – which suggests that the products were not initially engineered or designed for adaptations in different agro-ecological conditions. Most significant modifications are done on implements, as reported by 74% of respondents in Kilombero. In fact, most modifications are reported in Kilombero, versus Mbarali, and seem more prominent

on the trailers, with the aim of increasing carrying capacity, thus a reflecting a desire to use these machines for transportation. The implements' hitching system, used for attaching them to the tiller, is also subject to some modifications. In Kilombero 35% of owners reported modifying implements, versus 12% in Mbarali. Some of these modifications are done without regard to power generation or intended designs, contributing to failures, frequent breakdowns, or even injuries.

4.5 Effectiveness of power tillers

While power tillers were introduced in many districts through administrative directives, it is clear that they fit in certain production situations but not in others, a fact that was not keenly considered in this decision process. As a result, applications in each district are different, as are outcomes. The striking differences in the rate and type of power tiller use in Mbarali and Kilombero districts underscore this point. While both districts produce paddy, farmers in Mbarali district practice irrigation via runoff water and water from rivers. Irrigation schemes were gradually developed and formalized under the supervision of district authorities in the 1990s. The schemes are managed through irrigation organizations composed of small-scale farmers, organized on issues of water rights and credit access. The key agro-ecological feature is that when dry, clay soil is usually hard to till by hand hoe or power tiller. Thus, power tillers have been used more extensively for field activities in Mbarali district, where irrigation provides for wetter soil, compared to Kilombero district, and outcomes are different. By 2013, Mbarali district had about 44,000 acres under 80 smallholder irrigation schemes. The schemes vary in size, but an average of 3,000 smallholder farmers cultivates approximately 2,000 hectares of land.

Farmers in Kilombero district, by contrast, have continued to rely on rain-fed farming, so that the use of power tillers for ploughing is limited to a short period between the beginning of rains and planting time when soils are softer. This has made the use of these machines less prominent for field operations in Kilombero. Indeed, Kilombero farmers complain that these machines do not generate enough power to till the dry hard soil. This concern has also been echoed by others, including ministry officials. Table 4.1 shows the activities under which power tillers operate in the two districts.

Table 4.1: Usage of power tillers in Mbarali and Kilombero districts

	Activities	Mbarali		Kilombero	
		Respondents	%	Respondents	%
1	Farming	60	100	7	17
2	Transportation	46	77	31	66
3	Irrigation	6	10	0	0
4	Threshing	2	3	0	0
5	Grounded	0	0	8	17

Source: Survey data

Clearly, Mbarali's farmers use power tillers more directly on agricultural-related activities than is the case with Kilombero's farmers. Even though 77% of owners in Mbarali use these machines for transportation, in most cases it is for transporting farm inputs or produce to or/and from the farm, as explained by farmers as well as the District Agricultural and Livestock Officer. To the contrary, most transportation in Kilombero district is treated as a business in its own right and is not necessarily connected to farming activities.

The research also revealed that a significant proportion of power tillers in Kilombero district were reported as out of service. This is further corroborated by many formal complaints through the council by Kilombero district farmers. Documented evidence on power tiller malfunction availed by farmers as well as by the District Council vis-à-vis the supplier confirms dissatisfaction among farmer groups over tiller malfunctioning. In one such communication, in April 2011, the supplier was required by the District Council to visit the district in order to inspect and fix machine-related problems emanating from inaccurate technical specifications and operational and manufacturer shortfalls. A subsequent letter addressed to the District Executive Director from the chairperson of the Kiburutubu ward farmer group confirmed that the supplier's technician went to the site to inspect the machines and agreed with the cited problems, promising to fix them to the extent possible.

In terms of the contribution of power tillers to agricultural output and productivity, and the original intention of their use, results vary between the districts, reflecting the differences in the intensity of power tiller use in primary farming activities. Table 4.2 shows the responses of farmers in the two districts with respect to improved agricultural productivity, mainly in terms of crop yield improvements per unit of land.

In Kilombero district, respondents in the farmer group category indicated that power tillers had not increased their agricultural productivity because the farmers in the groups do not use them for agricultural activities. In the case of individual farmers, almost 50% of the respondents indicated that power tillers have improved agricultural productivity. The overall results, however, demonstrate that 57% of the respondents have not been able to improve their agricultural productivity. As explained earlier, this has been attributed to the fact that power tillers fail to generate sufficient power for ploughing the area's hard soils.

Table 4.2: Improved agricultural productivity

S/No	Response	Kilombero district				Mbarali district	
		Group	Individual	Respondents	%	Respondents	%
1	Yes	0	20	20	43	55	92
2	No	6	21	27	57	5	8

Source: Survey data

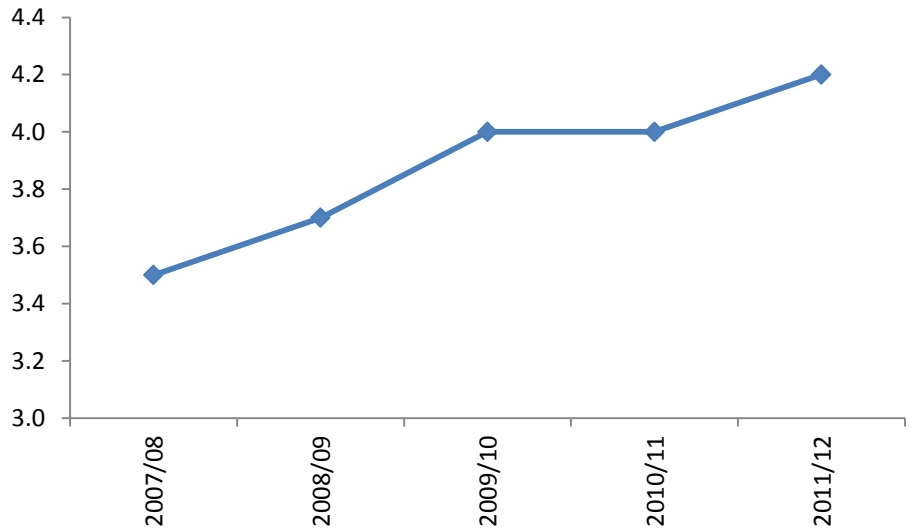
The 43% of respondents in Kilombero who indicated improved agricultural activities, linked power tillers to the improved ability to prepare a good seed bed. Hence, farmers use these machines to transplant paddy, contrary to previous planting techniques via broadcasting.

By contrast, the majority of respondents (92%) in Mbarali district cited improved agricultural productivity because power tillers enable them to prepare their farms

better and on time with the use of rotovators. The extra income obtained is used for purchasing fertilizers, thus considerably increasing the amount of paddy produced per unit area.

The few farmers (8%) who claimed a lack of productivity improvements associate the failure to late planting and failure to use sufficient fertilizer on their farms, rather than on machine malfunctions. Data provided by district authorities in Mbarali corroborate farmers' claims on increased productivity, especially of paddy, as shown in Figure 4.1.

Figure 4.1 Productivity change (yields) in Mbarali in tonnes/hectare 2007/8–2011/12



Data Source: Mbarali District Council

While productivity in some areas is reported to have increased as a result of power tiller use, it is possible that improvements may also result from other factors, although the available data cannot provide a detailed analysis of these. In addition, the sample size is not large enough for disaggregating by categories of land size, gender, or prior income for analysis of significant variations.

In terms of transportation cost, the results in Table 4.3 show that 91% of the Kilombero respondents and 80% of the Mbarali respondents have reduced their transport costs. The trailer has a seat, which allows the user to ride behind the power tiller instead of walking, as for the case of ploughing, harrowing, and puddling. Power tillers are therefore used for transporting various goods, including produce, firewood, water, building materials, etc. Moreover, of the 9% (Kilombero) and 20% (Mbarali) who claimed not to have benefited, none own power tiller trailers.

Table 4.3 Reduced transport costs

S/No	Response	Kilombero district				Mbarali district	
		Group	Individual	Total	%	Respondents*	%
1	Yes	3	40	43	91%	48	80%
2	No	3	1	4	9%	12	20%

Source: Survey data

*All respondents in Mbarali owned their own power tillers

In terms of area under cultivation, Table 4.4 demonstrates that a majority of the Kilombero respondents (57%) have not increased their area under cultivation, because they use their power tillers mostly for haulage. The Kilombero farmers who claimed to have increased their area under cultivation (43%) reported to do so because of flexibility in operational timing and reduced drudgery.

In Mbarali district 80% of farmers cited increased area under cultivation (Table 4.4). The increased areas vary from 1 ha to between 2 and 3 ha, and a few farmers have increased from 2 to 5 ha of paddy production. This has been attributed to availability of irrigation facilities (schemes) as well possession of power tillers and tillage implements, mainly ploughs and rotovators. Although Mbarali farmers appeared to have increased the area under cultivation, they reported a new challenge related to transplanting. Transplanting in Mbarali district is mainly done manually via hired labour. With an increase in cultivated area, the demand for hired labour has gone up, resulting in increased labour costs. Therefore, farmers in the area are looking for alternatives. Currently, farmers are working closely with the Mbarali District Council to explore ways of acquiring tiller-powered rice transplanters. While the increased labour cost is seen as a challenge, it is also a result of positive externalities arising from power tiller usage and the corresponding creation of an additional avenue for increasing area under cultivation and thus increasing farmers' incomes. Reduced transport costs and increased farmer incomes accruing from transportation services can also be considered as positive externalities.

Table 4.4: Increased area under cultivation

S/No	Response	Kilombero district				Mbarali district	
		Group	Individual	Total	%	Respondents	%
1	Yes	0	20	20	43%	48	80%
2	No	6	21	27	57%	12	20%

Source: Survey data

4.6 Institutional support for user knowledge and maintenance

At the time when power tillers were introduced, very little knowhow existed on

their use and maintenance, neither at the Ministry of Agriculture and other institutions nor among the farmers and power tiller operators hired by the farmers. For a variety of reasons, some owners preferred to hire other people as operators, while other owners operated themselves. As suggested by some officials, farmers were not sufficiently prepared on how to operate these machines under optimal conditions. Another official from the supplying unit likewise noted that part of the complaints from farmers emanated from a lack of user preparedness in understanding the conditions under which these machines could be used, resulting in unwarranted modifications.

Power tiller operators are vital in making the technology useful to both small- and medium-scale farmers. The key responsibilities of operators are to operate power tillers and to carry out normal routine maintenance that prevents them from frequent breakdowns and major repairs. Employing a competent operator ensures better returns on the investment. Thus, it is very important for an operator to be trained.

Results from Kilombero district reveal that very few power tiller operators (4%) acquired operational skills through formal training. This also applies to Mbarali district where it was revealed that none of the operators had an opportunity to attend formal training. The formal power tiller training in Kilombero was conducted over the course of three weeks at VETA Mikumi College, but unfortunately the study could not adduce reasons as to why other operators (96% for the case of Kilombero) did not have the opportunity to attend the training.

The other operators in both districts acquired operational skills via on-the-job training for different periods of time, ranging from one day to one year. Others acquired skills through one-day training sessions from power tiller suppliers. This was the case with operators of power tillers owned by farmer groups in Kilombero. Lack of adequate training could be one of the causes for why 50% of power tillers owned by farmer groups were out of service.

Similarly, there was no robust maintenance support system in many areas of the

country. Repair and maintenance, therefore, has been a challenging undertaking, although it has evolved over time. Repairs and maintenance are measures taken to sustain and restore the machine's performance and prolong its lifespan. Repairs are undertaken to replace the machine's malfunctioning or fatigued parts and include both scheduled and unplanned replacements. The term maintenance can be defined as the work done to ensure that failure does not occur before reaching a specified lifespan. This includes cleaning, daily oil checks, greasing, battery inspection, engine tuning, and general machine check-up. Maintenance work is typically graded on a daily and seasonal basis. Therefore, carrying out repairs and maintenance necessitates having a reliable source of spare parts and trained personnel.

In Kilombero district the study found that spare parts for power tillers are obtained from various places, including Ifakara, Mngeta, and Mang'ula villages. The distances from where the power tillers are based to spare part shops in these areas in most cases range from about 1 km to 80 km. However, if a spare part cannot be found locally it may be sourced from Iringa, Mbeya, or Dar es Salaam.

Farmers in Mbarali district purchase spare parts mainly from Chimala and Madibira villages, which are in the range of 0.2 to 30 km from most of power tiller owners. Other places include Mbuyuni, Ubaruku, Mkunywa Kijijni, Rujewa, and Mahango villages. On rare occasions farmers travel either to Iringa or Dar es Salaam to purchase spare parts.

Although Mbarali subsequently developed better local capacity for maintaining these machines, it presents an exception rather than the rule. First, because of high demand, the traders, especially Auto Sokoni Ltd, moved in quickly to set up a supply base within the district, with several agents also selling spare parts. Second, the agricultural training institute located at Igurusi in Mbarali district imparted knowledge and skills through field demonstrations on irrigation. Combining this and the service from local mechanics working with private suppliers, maintenance capacity was built, which led the farmers in the respective areas to even modify some tiller features. The most common form of modification, as noted earlier, was increasing the axle

load capacity on the trailers. This included replacing the original axles with stronger, locally fabricated axles and replacing the original rims with stronger and wider, locally modified rims.

It can generally be concluded that power tillers are simple machines that can be easily repaired and maintained in rural areas using existing skills. Their reliability in terms of undertaking proper work according to specifications, however, and identifying genuine parts and undertaking appropriate modifications is doubtful. The potential for positive externalities in raising local engineering skills exist, but the linkage between manufactures, suppliers, farmers, and machine operators as technology users is not robust enough to achieve the full theoretical benefits of frugal innovation. While the reasons for this lack of linkages could not be established, two hypotheses can be projected. First, the volume of tillers supplied in Tanzania are too small relative to global share for the manufacturer to invest in the desired linkage. Second, the national system of innovation is not robust enough to propel local adaptations of technologies and innovations. These may limit the effectiveness of this technology and its long-run demand in Tanzania.

4.7 Suitability of power tiller designs

The study found that power tillers in the study areas attracted young operators, a majority of whom are between 21 and 30 years old. This was revealed by 51% of the respondents in Kilombero and 60% in Mbarali districts. The fact that power tillers attract young people has a positive impact on reducing the rural to urban migration. The current trend has been for educated and young people to migrate from rural to urban areas to liberate themselves from drudgery associated with the use of hand tools in agriculture, leaving the older people in the villages.

The suitability of power tillers is their motorized source of power, their relatively small size, and low price. Power tillers can also be hitched to different implements for various operations, including tillage, water pumping, threshing, transportation, etc. The added seat when using a trailer likewise makes power tillers suitable for transportation purposes.

Despite these design features the technology was not fully accepted in all places where it was introduced. In some areas like Mbarali district the technology was well received, although a lot of modifications were also made. In Kilombero district the technology proved to be somewhat of a failure as it could not perform as expected in primary activities in agriculture, principally because of the lack of engine power for tilling hard soils.

5. The case study's contribution to the main research programme

The broader hypothesis of the main research programme is anchored on the important role played by embeddedness of local knowledge and technology networks in re-engineering of high-value products in ways that can make them attractive and useful by those in the BoP, potentially building a high-volume market for manufacturing firms. The absence of this embeddedness of local knowledge is likely to constrain successful re-engineering or even the adaptability of the products concerned. This case study has demonstrated how the lack of embeddedness of local knowledge and agro-economic conditions in power tiller design has rendered them ineffective in areas that do not have complimentary interventions, notably the irrigation scheme. Local knowledge has been applied *ex-post*, mainly in modifying certain functions to suit other needs that were considered secondary, particularly transportation.

Few efforts have been made to promote local assembly or customization of power tillers, except a failed attempt by one private company located in the Western Lake zone to produce power tillers. The Centre for Agricultural Mechanization and Rural Technology (CARMATEC) based in Arusha, a state institution established in 1981, should have played a leading role in identifying appropriate machines and technologies or proposing customizations to make tillers work better for the intended purposes. Yet the centre seems to have played only a minor role in this particular process. Only a few machines that were procured directly through the government tender or specific projects were passed through CARMATEC for testing and advice. The majority of these machines, especially those imported by traders, did not use CARMATEC, perhaps because the law does not strictly require all imported agricultural machinery to be tested and approved by CARMATEC.

The study confirms the hypothesis of generalized failures related to technical design, reflected in the underpowered motors relative to the hardness of the dry clay soils that characterize many farming districts in Tanzania. The institutional limitations are also evident in the supply-driven approach, which was not conscious of agro-ecological differences and the importance of scaling up user training on mechanization and maintenance systems to achieve positive results. The demand for power tillers and the corresponding positive contribution to farming and livelihoods in Mbarali does not reflect a routinized institutional platform for promoting this innovation, which has also been the case in many other districts for which power tillers have been promoted. In addition, the manufacturing firms have not responded to the needs arising from this diversity in the agro-ecological conditions in Tanzania.

6. Conclusion

This study on power tillers was carried out as a pilot project for a broader research project led by Leiden-Delft-Erasmus (LDE) consortium. The broader project intends to focus on the role of innovation, technology transfer, and technology networks in Africa's economic transformation, using the notion of frugal innovation. This pilot project was carried out to ascertain how different actors were involved in introducing and applying power tillers in Tanzania. Overall, the study suggests that power tillers in Tanzania were introduced using top-down, state-induced innovation that was not adequately informed by technical and agro-ecological differences in Tanzania. As a result, power tillers were imported from various Asian countries, and no re-engineering was carried out to match their designs to local needs. In addition, no thorough preparation was put in place in terms of identifying user needs, training operators, and setting up maintenance and service systems. Frugal innovation entails more than just reducing the complexity and costs of products or services while retaining basic functionality. It also entails a functional interface between technological and institutional dynamics.

The end result is that in some places the technology was adopted with some

modifications, whereas in others the technology was not suitable for the purpose that was initially conceived. Local innovation did, however, result in positive externalities, where secondary use of transportation and hauling goods prevailed over primary farming functions. Power tillers can therefore provide solutions to primary concerns on agriculture mechanization for smallholders only where agro-ecological conditions commensurate with the current technical design of power tillers. The study also suggests that the political economy of agrarian transformation needs to address the diverse needs of the farmers and package interventions that are appropriate to agro-ecological conditions and socio-economic environments that may be crop specific, market specific, or locational specific.

Further research is needed to benchmark systems and processes involved in product designs or re-design that embed characteristics of frugal innovation, seeking to make such products functional in the local circumstances, robust for the operating conditions, user friendly, and affordable to those at the bottom of the pyramid. Such research will provide room for benchmarking different products and institutional processes involved in bringing innovation to bear for local economic development.

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