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Synopsis: Unlocking agricultural efficiency:
A stochastic frontier analysis of smallholder farmers in Rwanda

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This study assesses the technical efficiency of smallholder farmers in Rwanda, with a focus on maximizing crop output value and identifying the socioeconomic drivers that shape technical efficiency.

- The analysis shows that farmers are operating at just 45% of their potential productivity, revealing substantial opportunities for increasing crop output value.
- Key drivers of crop production value include effective fertilizer use, pesticide application, labor, seed usage, and land size.
- The study finds that household size, access to extension services, participation in the Smart Nkunganire System, irrigation practices, land consolidation, land ownership, and monocropping all positively influence technical efficiency. However, female-headed households, wage income, and market distance have a detrimental impact on efficiency.
- These findings underscore the need for targeted interventions to optimize resource use, improve labor allocation, enhance farm management practices, and strengthen access to advanced inputs, extension services, and government programs. Such measures will contribute to increased agricultural productivity and long-term transformation in Rwanda's smallholder farming system.

Overview

Agriculture plays a crucial role in Rwanda's economy, supporting the livelihoods of about 70% of the population and contributing approximately 27 percent to national GDP. Despite government initiatives such as the Crop Intensification Program (CIP) and the Smart Nkunganire System (SNS), designed to enhance resource access and boost productivity, smallholder farmers continue to face challenges that reduce their potential. These challenges include limited access to modern inputs, lower productivity, and vulnerability to climate change. This study examines the sources of technical inefficiency among smallholder farmers, with a focus on potential drivers that could contribute to improving crop output values. Using stochastic frontier analysis (SFA), the study assesses the technical efficiency of smallholder farms and identifies key factors influencing productivity, such as fertilizer use, pesticide application, labor, seed, and land size.[1]

The findings reveal that farmers operate at only 45% of their potential productivity, highlighting significant opportunities for improvement. Additionally, a Tobit model analysis underscores the important role of socioeconomic factors, such as household characteristics and participation in agricultural programs, in shaping efficiency outcomes. The results suggest the need for targeted interventions to optimize resource use, improve labor allocation, enhance market integration, strengthen access to extension services and government programs. By addressing these inefficiencies, Rwanda can help smallholder farmers reach their full productive potential, contributing to the country's agricultural development objectives and improving the livelihoods of its farming population.

Technical efficiency and key drivers of crop output value among smallholder farmers

The analysis reveals several key findings that have important implications for policy interventions aimed at improving agricultural production value and efficiency. The average technical efficiency (TE) score is 0.45, indicating that farmers are producing only 45% of their potential output value given their levels of input and technology. Additionally, only 43% of households are achieving a TE above 0.5, indicating that most farms are operating at less than 50% efficiency, leaving significant room for improvement in optimizing their input use and production practices. Lower efficiency may be partly attributed to the emphasis on subsistence and the cultivation of lower-value crops, limited access to improved inputs, lack of technical knowledge, inefficient resource allocation, or external constraints like climate variability and market access issues. All these factors limit the optimization of crop output value.

The study also identified several key drivers of crop output value among smallholder farmers. The use of fertilizers and pesticides significantly enhance crop output value, underscoring the importance of these inputs in boosting productivity. However, excessive use can raise environmental concerns, emphasizing the need for careful management and balanced use to achieve sustainable production. An increase in land size initially contributes to higher output, but its impact diminishes beyond a certain threshold, suggesting that larger landholdings may not always lead to proportional increases in productivity. To address this, policies should encourage land optimization through agroecological practices and integrated land management strategies, ensuring that productivity is maximized while maintaining sustainability.

[1] For a more detailed analysis, see Working Paper #17, Unlocking agricultural efficiency: A stochastic frontier analysis of smallholder farmers in Rwanda.

Table 1: Key determinants of crop output value using farmers' technical efficiency

Input variables	Coefficient	Standard error
Seed cost	0.01	0.02
Fertilizer and pesticide cost	0.31***	0.07
Labor cost	-0.03	0.06
Farm size	0.64***	0.03
½ (Seed cost)^2	0.09**	0.04
½ (Fertilizer and pesticide cost)^2	-0.01	0.02
½ (Labor cost)^2	0.06***	0.01
½ (Farm size)^2	-0.18***	0.05
Seed * Fertilizer and pesticide cost	-0.01	0.02
Seed * labor cost	-0.02	0.02
Seed cost * farm size	-0.002	0.02
Fertilizer and pesticide * labor cost	-0.003	0.03
Fertilizer and pesticide cost * farm size	-0.06*	0.03
Labor cost * farm size	0.07**	0.03
Constant	5.4***	0.1
Observations	2,006	

Source: Authors' calculations.

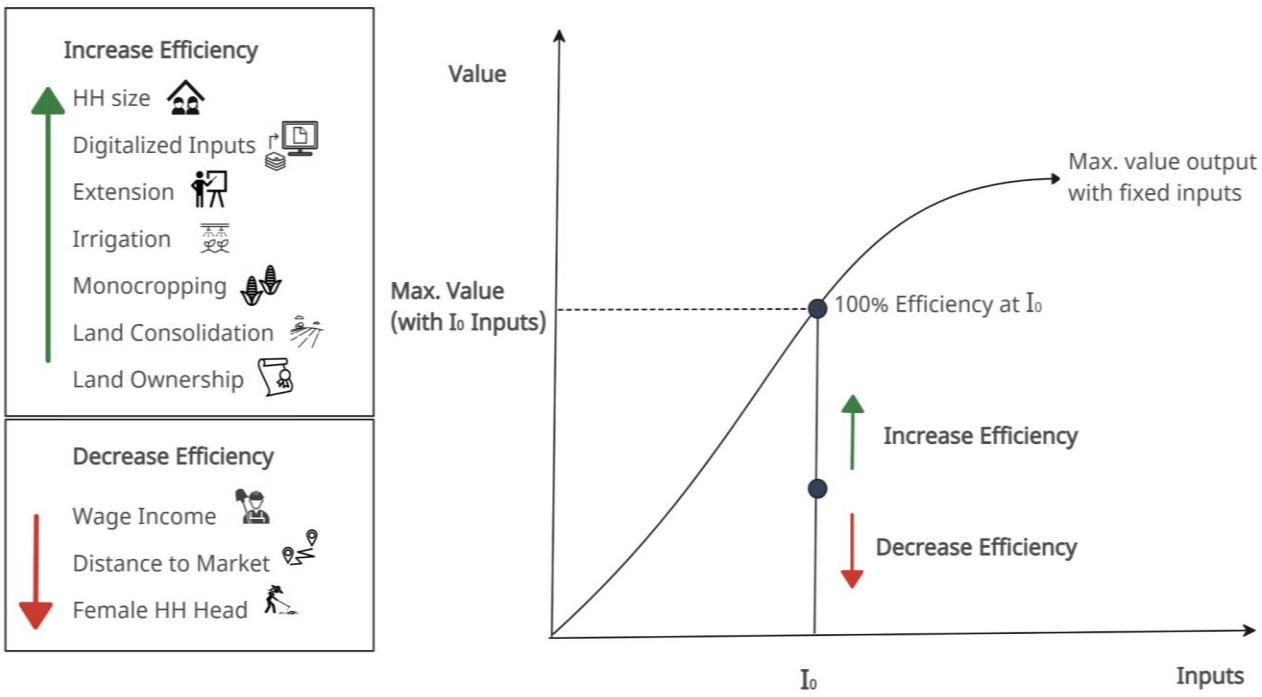
Seed use was found to have a non-linear relationship with crop output, suggesting the need to identify specific thresholds of use for attaining maximum efficiency. Therefore, effective seed management, supported by extension services, is essential to improving crop production value. While labor alone does not significantly affect crop output value, its effectiveness increases when combined with other inputs and can be optimized according to farm size. This highlights the importance of efficient labor utilization and the integration of labor with complementary resources to enhance productivity.

The findings call for targeted interventions to enhance input access, land use, and labor efficiency. Strengthening the Smart Nkunganire System, expanding extension services, and promoting farmer cooperatives can improve input use and affordability. Land optimization requires targeted agroecological practices, strategic planning, and secure land tenure. Labor efficiency can be boosted through mechanization, training, and youth and women incentives. These measures will enhance crop production value and drive sustainable agricultural growth for Rwanda's smallholder farmers.

Factors influencing crop output technical efficiency

The results indicate that larger household sizes positively affect technical efficiency (TE), as family labor plays a crucial role in improving farm management and optimizing input use, especially when external labor is limited. Access to extension services also enhances TE by providing valuable training on farming practices. Additionally, participation in the Smart Nkunganire System improves efficiency by enhancing access to subsidies and digital resources, though challenges such as connectivity and digital illiteracy remain. Irrigation significantly boosts TE, highlighting its importance in optimizing crop production value, particularly in climate-affected areas.

Figure 1: Determinants of technical efficiency in crop output across Rwanda's farm types: Tobit model insights



The study revealed that practicing monocropping positively impacts TE by streamlining resource use and enhancing farm management, though it also poses risks such as pest vulnerability and soil nutrient depletion. Land consolidation improves TE by reducing fragmentation and optimizing resource use, while secure land ownership boosts efficiency by encouraging investment and effective land management. Conversely, wage income negatively affects TE as households may divert focus from farming to wage labor, reducing input utilization and farm management.
Market distance likely hampers TE and this may be explained because longer distance to market are associated with increases in transportation and transaction costs, limiting access to inputs and markets, and reducing responsiveness to market demand. Finally, female-headed households experience lower TE due to gender-related barriers in accessing resources, underscoring the need for targeted interventions to address these disparities and enhance productivity. These findings emphasize the importance of policies supporting family labor, extension services, digital platforms, irrigation, land consolidation, gender aware policies, and improved access to markets and resources.

Policy recommendations

To enhance agricultural productivity and sustainability, farmers, stakeholders and policymakers should implement targeted interventions addressing labor utilization, agricultural extension services input access, land security, market integration, gender inclusion, irrigation and climate resilience.

1. Optimizing Labor Utilization

- Provide training on efficient farming practices and task management, with incentives for hiring additional labor during peak seasons.
- Support labor-sharing initiatives to reduce individual burdens and promote mechanization.
- Offer targeted subsidies for labor-saving technologies, particularly for aging farmers and female-headed households.
- Encourage youth engagement in agriculture through skills development and financial incentives.

2. Strengthening Agricultural Extension Services

- Enhancing Customized Agricultural Extension System (CAES) implementation will improve coordination among stakeholders to provide tailored advisory services
- Promote resource optimization, market-oriented approaches, and climate-smart agriculture.
- Prioritize training in advanced crop management, and high-value crops.
- Promote Public-Private Partnerships (PPPs) and digital solutions to attract private investment, scale up extension services, and expand farmer outreach.

3. Improving Access to Agricultural Inputs

- Scale up the Smart Nkunganire System for equitable input distribution.
- Enhance digital infrastructure to ensure timely delivery of inputs.
- Strengthen farmer cooperatives to facilitate collective procurement and market access.

4. Enhancing Irrigation and Climate Resilience

- Invest in small-scale irrigation infrastructure and provide training on water management.
- Offer subsidies to support irrigation expansion and promote climate-smart agricultural practices.
- Encourage monocropping systems with optimized resource allocation through training and support programs.

5. Strengthening Land Use and Security

- Raise awareness and provide technical support for effective land consolidation programs.
- Promote group land ownership models, land leasing programs, and land banks to enhance security.
- Improve land certification processes to facilitate investment and access to finance.
- Link land security to credit access to enable smallholders to secure financial resources.

6. Promoting Gender-Inclusive Agricultural Policies

- Implement gender-sensitive extension services to address the unique challenges faced by female farmers.
- Support women-led cooperatives and introduce policies that ease women’s access to credit and land ownership.
- Provide childcare services to enhance women’s participation in agriculture.

7. Enhancing Market Access and Price Stability

- Improve rural infrastructure, including storage facilities and transportation networks.
- Develop digital marketplaces to connect farmers with buyers and minimize post-harvest losses.

8. Integrating Wage Income with Farming

- Implement flexible farming support programs that integrate wage income and agriculture.
- Provide financial literacy training to help farmers reinvest in agricultural activities.

9. Implementing Effective Monitoring and Evaluation

- Establish robust, data-driven monitoring systems to refine policies and improve efficiency.
- Conduct regular assessments to ensure interventions effectively enhance crop output and technical efficiency.

10. **Enhancing Farmer Engagement in Policy Dialogue and Implementation**
    - Facilitate and empower farmers, to actively participate in agricultural policy dialogues, provide informed feedback on implementation challenges, and collaborate with policymakers to develop and refine effective, inclusive, and sustainable farmer-centered policies.

By adopting these measures, the Government of Rwanda and stakeholders can enhance agricultural efficiency, improve crop output value, ensure equitable benefits, and promote sustainable livelihoods for smallholder farmers.

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