This brief focuses on the profitability of adopting technology for farmers and small and medium-sized enterprises (SMEs) and examines the financial sustainability of these investments over time. The evidence presented here can help researchers and policymakers better understand farmer characteristics and favourable conditions for technology adoption, identify constraints inhibiting adoption, and draw lessons to replicate or scale successful policies around technology adoption in agriculture.

New technologies in low-and-middle-income countries (LMICs) show mixed results around their effectiveness to enhance long-term productivity and profitability of smallholder farmers and SMEs, largely due to low take-up and uncertain distribution of welfare gains among adopters. While large and medium-sized farms and firms may have the resources to adjust operations and production when adopting new technologies, smaller ones are often more constrained to adopt certain decisions and may respond better to context-specific interventions.

While there is a growing body of experimental and quasi-experimental evidence to measure the effect of policies on farmers’ and firms’ technology adoption decisions, a limited number of studies address the question of profitability. Specific evidence about why farmers do not invest in some technologies, in addition to improved data collection and methods to measure profitability more accurately, will help bridge this gap. It is also important to consider how different interventions yield heterogeneous results due to differences in take-up or farmer ability to use technologies properly to drive sustained profits. Based on this framework, the brief takes stock of the rigorous evidence used to examine which farmers adopt technologies, which technologies are profitable and under what conditions, and how farmers can sustain agricultural investments and profits.
The brief reviews more than 30 experimental and quasi-experimental studies around agricultural technology adoption to address key questions facing policymakers such as:

- How does technology adoption increase profitability and complementary investment for smallholder farmers and SMEs in LMICs?
- Over what timeframe do the impacts of technology adoption take place for smallholder farmers and SMEs in LMICs?

Building on research reviews by Bridle et al. (2020), Magruder (2018), and FAO (2021), which identified the common barriers to technology adoption, the brief aims to identify the constraints found in investing in agricultural technologies. It identifies key constraints such as credit and savings, risk and uncertainty, information, input and output market inefficiencies, and opportunity cost to labour. For example, new technologies may be more labour-intensive and divert resources from other, non-farm sectors making it less likely for farmers to adopt them (Scognamillo et al., 2022).

The evidence summarized in this brief is timely, given the increasing awareness and global urgency to address climate change's impacts on agriculture in LMICs, including seasonal fluctuations and weather shocks, as well as agriculture's role in greenhouse gas emissions (UNFCCC, 2021). This is especially the case in sub-Saharan Africa where rainfall is becoming more intense and unpredictable. In turn, this is shrinking the share of arable land for farmers and leading to potentially adverse economic effects. For instance, under current weather trends in the region, by 2030, wheat production is expected to decline by nearly 20 percent from 1998–2002 yields (Munang and Andrews, 2014). Relatedly, a 1°C increase was found to decrease per capita income growth in the region’s 18 fragile states by 1.8 percentage points between 1980 and 2019 (Maino and Emrullahu, 2022). In this context, policymakers must identify conditions that enable smallholders and SMEs to invest in cost-effective agricultural technologies that help address or avoid exacerbating the effects of extreme climatic events. Policymakers must also emphasize technologies that enable farmers to bounce back from these shocks and reduce agriculture’s environmental footprint while boosting, or maintaining, agricultural output and productivity.

Context matters: heterogeneous impacts of technology adoption on farmer and SME profitability

New agricultural technologies may need to be introduced alongside other mechanisms that can help farmers overcome barriers to their adoption.

Because smallholder farmers and SMEs face multiple barriers to technology adoption at the same time – such as less developed markets, limited liquidity, and lack of information – the existence of a new technology alone is often not enough to stimulate its adoption. For example, capital intensive technologies, including mechanized equipment, irrigation equipment, and storage facilities, can dramatically reduce the time and energy spent by farmers cultivating their crops. Potential constraints to technology adoption or investment in such technologies include the initial cost of inputs, as well as recurring service or maintenance costs. Likewise, less capital-intensive technologies such as improved storage bags and planting applications can improve yield quality and protect crops from insects, disease, and failure. Despite higher prices relative to their traditional counterparts, adopting these new technologies generally yields sufficient, and in some instances higher returns for farmers. Yet take-up can lag due to financial constraints or in the case of limited knowledge about the technology.

Farmers are more likely to adopt technologies under intervention that address barriers such as information asymmetries and capital constraints, rather than those that simply make the technology available.

In Ethiopia, Vandercasteelen et al. (2018) introduced row planting technology in a promotional campaign to boost productivity of the country’s most important crop, teff. Although row planting has been shown to increase teff yields, the increase outweighed the extra labour costs in the first year if annual yields increased by more than 8 percent. In this case, neither yields nor profits increased, while labour requirements increased and labour productivity declined. Vandercasteelen et al. argue that increasing the availability of promotional campaigns and training for farmers would help them learn about the technology and implement it effectively, thereby enhancing adoption. They also argue that policymakers take into account labour requirements and on-farm constraints before scaling up the adoption of row planting technology.

In Uganda and Ethiopia, respectively, Omotilewa et al. (2019) and Alemu et al. (2021) observed farmers’ adoption of hermetic storage bags. These bags are durable for storing food safely for an extended period and eliminate maintenance costs such as insecticide treatment. The hermetic bags would allow farmers to save their goods to later sell when prices are high, and therefore make a profit at market (Alemu et al., 2021). However, the bags were five times more expensive than traditional woven bags (USD 2.50 compared to USD 0.50) and were not widely available on the market. Both caused considerable uncertainty amongst farmers about the potential payoffs and effectively reduced take-up rates. Meanwhile, Ndegwa et al. (2016) found that storage bags became profitable if used for more than four months on average, and for at least four years.

The above factors from these hermetic storage bag interventions suggested a need to accompany awareness campaigns about the bags’ ability to maintain crop integrity and therefore profitability during storage, or cost reduction programmes (e.g. through supply chain improvements or subsidies) to incentivize adoption as the technology is rolled out to the public. These conclusions corroborate the findings of Shilbach et al. (2015) in western Kenya, who found that an information campaign about a profitable fertilizer measuring spoon was key to overcoming information hurdles to spread smallholder knowledge and adoption of the technology.

Vouchers can help farmers overcome cash constraints and stimulate take-up of otherwise expensive technology that can increase their productivity and income potential. Caunedo and Kala (2021) encouraged smallholder farmers to practise mechanization in India by distributing vouchers to subsidize equipment rentals. Vouchers averaged USD 36 – about 5 percent of farmers’ yearly agricultural revenue of USD 653.80 – and farmers used USD 28 (78 percent) of the subsidy amount. This practice has significantly increased mechanization rentals by 30 percent. While the increase in technology adoption through mechanization had no impact on income or profitability, it has led to significant labour savings. Thanks to mechanization, families saved approximately 1.5 hours per acre per day of labour, previously used on land preparation. This allowed farmers to pursue non-agricultural activities, although the study does not specify the activities or whether they generated additional income.
Similarly, through the Program for the Support of Innovation in Agricultural Technology (PATCA) in the Dominican Republic, vouchers reduced the purchase price of irrigation equipment and improved pasture technology, and in turn increased farmer adoption of such technologies by more than 60 percent. Farmers who adopted rotational grazing increased their incomes, and farmers who adopted irrigation changed their crop portfolios from temporary crops to permanent crops (e.g., fruit trees). While this change led to less output by the end of the intervention because permanent crops require more time to harvest, they were still in the growing stages at the end of the intervention. This suggests that the reduced output and income were most likely temporary, and would translate into higher incomes in the medium and longer term.

Certain climate-smart technologies such as agroforestry, and climate-smart fertilizer and its application have environmental benefits but limited profitability potential in isolation. The positive investment effects may increase when these technologies are offered, with significant financial incentives to stimulate adoption, or are bundled with another potentially profitable technology.

In Zambia, researchers marketed a tree species called faïderba albida to maize farmers to plant on their plots (Jack et al. 2015). While the initial take up was moderate due to discounts, follow-through adoption was significantly lower once farmers realized the investment costs associated with maintaining the trees. For instance, the average labour cost of maintaining the tree per half hectare of land was USD 19 in the first year, while the annual value during that period was only around USD 2. In addition, yield gains associated with the tree’s natural fertilizer properties (a 100 percent to 400 percent increase) would take seven to ten years to realize. The researchers did find that offering a financial reward to farmers conditional on follow-through was effective in inducing higher levels of follow-through than the initial discount alone. Thus, while conditional incentives are potentially challenging to keep track of, they offer an opportunity for policymakers to stimulate the sustained adoption of a long-term investment technology.

Liverpool-Tasie et al. (2022) partnered with a private firm to advocate for the adoption of a climate-smart fertilizer – Urea Super Granule (USG) – in Nigeria. The firm marketed the climate and cost benefits of USG to the public while also offering farmers a 25 percent discount on it. Marketing and the discount increased adoption of the climate smart variety of fertilizer and decreased use of the other variety. Despite high adoption, USG had no effect on profits, suggesting that an improved adoption of complementary inputs and practices may be needed. The authors advocate pairing a capital-intensive technology with the potential to transform the farmer’s production frontier alongside USG.
Factors such as markets, institutions or demographics can stimulate or weaken investment in a technology.

Occasionally, farmers face certain challenges inherent in the community that prevent investment in a new technology, no matter its potential profitability, such as long distances to markets or gender disparities in access to technologies. The geographic location and demographics of a farming community, and the market within which it operates, as well as the institutional framework may shape the opportunities and challenges of sustained technology adoption and agricultural investment. For instance, whether or not a market facilitates economies of scale play a role in the profitability of a given technology.

Kotu et al. (2019) assessed the profitability of metallic silos in the United Republic of Tanzania, which have a large-fixed price. They found that silos larger than one-ton capacity were profitable, especially in locales where seasonal grain prices and price gaps were high to offset the high investment cost. On the other hand, smaller metallic silos did not pay off for farmers. Altogether, silos were profitable for those who had high enough economies of scale to afford a large silo. The researchers suggested that to reduce cost barriers to silo adoption, policymakers and silo producers could focus on introducing plastic silos to farmers, which are cheaper than metallic silos and similarly effective against storage pests.

Group savings clubs can provide significant opportunities for members to invest in and profit from new agricultural technologies. Because of the local nature of savings clubs (e.g. demographics, investment barriers, etc.), not every savings club is going to experience the same outcomes. In western Kenya, Aggarwal et al. (2018) found that hermetic storage bags generated 15 percent higher revenues for rotating savings and credit associations (ROSCAs), with each ROSCA securing revenue gains at least USD 98 compared to USD 35 in costs, a USD 63 profit. Use of the storage bags remained high over two years later.

The introduction of a productive technology could provide farming communities in countries with the means to stimulate productive investment in the future. In Nepal, a country with labour shortages and low agricultural productivity, Park et al. (2018) introduced a low-cost, chest-mounted seeder and fertilizer to smallholder wheat farmers to enhance yields. As opposed to hand-tilling practices, the technology increased yields and seedling density. This consistency and efficiency in application of seeds and fertilizer led to more consistent yields in and across fields than hand tilling (which had high variability in production) and consequently, more predictable profits.

In Bangladesh, Chakravorty et al. (2019) introduced a perforated plastic pipe technology to be used in alternate wetting and drying (AWD) and evaluated if it saved water and raised profits for farmers. Hourly water pricing – as compared to seasonal fixed pricing – increased the purchase of the pipe at its four highest prices by 35 percent. Yet the impacts of the AWD pipe were limited: the pipes saved water and increased annual farmer profits by USD 23 per acre (a 7 percent increase) when water was priced at the margin and by volume. Alternatively, farmers who paid a fixed price for water did not experience any financial benefits from the pipe. Ultimately, long-term take-up of the AWD pipe was low, with only 20 percent of purchasing farmers using it following the intervention.

A hillside irrigation intervention in Rwanda illustrates that productive and profitable technologies are not always sufficient for technology adoption if there are market failures. Jones et al. (2020) found that profits increased by 44–71 percent as a result of switching from perennial bananas to rotating crops, but the switch caused production to be more labour-intensive. Consequently, hillside irrigation suffered from low take-up as farmers could not expand labour allocation beyond the household due to a shortage of outside labour. The results highlight that policymakers should pay more attention to the factors of production and the institutional context of technology adoption, as well as the institutions involved in strengthening them before introducing new technologies.

Trends around technologies in Nepal also indicate broader negative impacts that have the potential to restrict agricultural opportunities for women and contribute to substantial food losses. Paudel et al. (2020) found that the adoption rate of mini-tillers was 37 percent overall, but only 18 percent in female-headed households (compared to 56 percent in male-headed households). Male-headed households tended to live closer to markets and had larger social networks connected to those markets, and were thus better able to leverage the benefits of the technology. Enhancing market access for women and through female-targeted mechanization programmes could help minimize the gender differential in adoption and give women farmers greater potential for realizing the financial benefits of mechanization.

Paudel et al. (2019) also found that while wheat farmers adopted rotavators at a high rate – especially farmers who relied on off-farm income primarily and thus perhaps paid less attention to farming practices and outcomes – the technology reduced yields by up to 15 percent. This caused farmers to potentially lose between USD 93 and USD 101 per hectare per season in gross margin (337–445 percent), a sum that increased with long-term usage of the technology. Despite the disconnection between high adoption rates and money lost, farmers were more likely to adopt the rotavator because it saved tillage costs and labour, as hired labour was scarce and expensive at the time of the study.
Adverse effects of climate change may require transitions from conventional agriculture to ensure farmers’ long-term productivity, profitability, and resilience.

Conservation agriculture (CA) technology has been implemented in many countries as a low-cost, labour-saving, and climate friendly alternative to conventional tillage (CT). The studies reviewed indicate that CA could be a promising technology for controlling soil degradation, mitigating drought, increasing crop yield, and reducing production costs. Moreover, CA also demonstrated higher net returns for farmers by significantly reducing labour costs and production costs (like land preparation and weeding).

Ngwira et al. (2013) and Micheni et al. (2015) designed interventions to test the profitability of CA systems in East Africa. In Malawi, Ngwira et al. (2013) found higher net returns for farmers using CA technologies through reduced labour and production costs, but also higher overall variable costs compared to traditional tillage (at most USD 483 vs USD 398 in Lemu and at most USD 883 vs USD 670 in Zidyana) meaning that the fear of higher variable costs would likely discourage farmers from investing in CA, despite its profitability. In Kenya, Micheni et al. (2015) found that while CA initially had higher production costs than CT, costs reduced over time to where CA was around four times less expensive than CT in year four of the study. Due to lower labour costs and higher yield increment, CA was more profitable, and the researchers reasoned that the higher revenues from farming and more free time could lead to off-farm income-generating activities.

Four studies examined the profitability of CA technologies in India (Aryal et al., 2014; Jat et al., 2014; Das et al., 2014; Parihar et al., 2016), and all found that CA increased farmers’ net returns compared to CT. Aryal et al. (2014) found a USD 79 per hectare decrease in costs from refraining from preparatory tillage and irrigation. They calculated a zero-tillage adoption for both rice and wheat provided a higher net return over absolute CT. Jat et al. (2014) calculated a USD 459 per hectare per year additional net return in zero tillage rice-wheat systems over absolute CT rice-wheat systems (which had one of the lowest net returns at USD 197 per hectare per year), and Parihar et al. (2016) found zero tillage technology increased farmers’ net profit by 31 percent and enhanced water productivity by over 19 percent. Das et al. (2014) found that while the costs of cultivating cotton-wheat plots with CA were higher than CT, net returns were higher for CA plots. Additionally, Aryal et al. (2014) and Parihar et al. (2016) found that zero-till technology reduced carbon dioxide emissions and enhanced water productivity. They argue that CA technologies have the potential to bring down income insecurity, increase food security, and mitigate climate change.
Main takeaways

The barriers that prevent take-up of agricultural technology are not insurmountable. While interventions do not always present a clear economic or financial case to invest in agricultural technologies from a private farmer perspective, studies illustrate conditions under which technologies would be profitable. These conditions or interventions include initial subsidies, improved markets, information campaigns about products and how they may increase profits, or programmes to promote continued usage over longer time periods (over which farmers can recoup initial costs).

While several important trends emerge from the literature, there are few widely generalizable or definitive conclusions due to the specific nature and context of technologies and studies. Moreover, because of the limited scope of this brief, the number of studies available on each topic does not necessarily reflect the relative importance or effectiveness of that technology. Additional studies are likely needed to draw broader lessons about agricultural technologies that receive large investments by governments or international financing institutions.

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<tr>
<td><strong>1</strong></td>
<td>Technology adoption and farm investment trends are inherently shaped by the realities of the farming community; opportunities and challenges are unique and must be accounted for by policymakers and researchers before rolling out a new technology.</td>
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<td><strong>2</strong></td>
<td>The most common constraints to technology adoption are liquidity constraints, market constraints like poor supply chains, limited knowledge and capacity constraints, labour constraints, and farmer uncertainty about a technology’s viability. Access to finance, increased attention to labour market dynamics, and appealing to farmers about their needs can help reduce these constraints.</td>
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<td><strong>3</strong></td>
<td>The effects of climate change may require transitions from conventional agriculture to ensure farmers’ long-term productivity, profitability, and resilience.</td>
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<td><strong>4</strong></td>
<td>Many technologies require a complement (i.e. bundling) to stimulate farmer adoption.</td>
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<td><strong>5</strong></td>
<td>While some studies disaggregate results by farmer characteristics, the heterogeneous effects on adoption rates, take-up rates, and profitability disaggregated by gender, age, household composition, and education level have not been addressed adequately to allow us to draw broad conclusions, leaving a wide knowledge gap.</td>
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<tr>
<td><strong>6</strong></td>
<td>Access to markets, time constraints, and limited social networks that contribute to improved agricultural productivity and improved livelihoods remain barriers for women farmers. Disentangling these barriers and the effects they have on women’s technology adoption and learning is a key priority area for future research.</td>
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<td><strong>7</strong></td>
<td>Several evaluations show that farmers adopted technologies that save time and labour, enabling them to maximize opportunities for off-farm activities and income.</td>
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<td><strong>8</strong></td>
<td>Many rigorous impact evaluations of technology adoption programmes do not collect detailed data on the cost of production or profit. This information gap undermines understanding of the conditions under which the profitability of a new technology can be assessed.</td>
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References


Abbreviations and acronyms

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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AWD</td>
<td>alternate wetting and drying</td>
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<tr>
<td>CA</td>
<td>conservation agriculture</td>
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<td>CT</td>
<td>conventional tillage</td>
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<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<td>IPA</td>
<td>Innovations for Poverty Action</td>
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<td>LMICs</td>
<td>low- and middle-income countries</td>
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<td>ROSCA</td>
<td>rotating savings and credit associations</td>
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<td>SMEs</td>
<td>small and medium enterprises</td>
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<td>USG</td>
<td>Urea Super Granule</td>
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