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Economics of Digital Agricultural Extension A Review of ICT-based Advisory Services and Their Farm-level

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ABSTRACT

The proliferation of information and communication technologies (ICTs) across the developing world has fundamentally altered the landscape of agricultural extension services. This paper provides a systematic review of empirical evidence on the economics of digital agricultural extension, synthesising findings from over 80 peer-reviewed studies and programme evaluations published between 2005 and 2024. We examine the cost structures, adoption dynamics, productivity effects, market integration outcomes, and broader welfare implications of ICT-based advisory platforms, including SMS services, interactive voice response (IVR) systems, mobile applications, video-based dissemination, and hybrid digital-human models. Our analysis reveals that digital extension channels consistently reduce the per-farmer delivery cost by 60–85% compared to conventional face-to-face advisory systems, while simultaneously expanding reach by one to three orders of magnitude. Rigorous impact evaluations report average yield gains of 8–23% and farmgate price improvements of 5–16% attributable to ICT interventions, translating into benefit-cost ratios (BCRs) ranging from 2.5:1 to 6.8:1 in smallholder contexts. However, returns are highly heterogeneous and conditioned by infrastructure quality, digital literacy, gender dynamics, crop type, and the complementarity of market institutions. We propose a multi-dimensional analytical framework for evaluating digital extension investments and offer evidence-based policy recommendations for governments, development organisations, and private-sector actors seeking to optimise farm-level returns from ICT deployment.

Keywords: digital extension; ICT4Ag; agricultural advisory services; mobile phones; smallholder farmers; impact evaluation; benefit-cost analysis; technology adoption

INTRODUCTION

Agricultural extension—the systematic transfer of knowledge, technologies, and management practices from research institutions to farming communities—has for decades been one of the most contested investments in rural development policy. Classical public-sector extension systems, modelled on the Training and Visit (T&V) approach championed by the World Bank through the 1980s, proved fiscally unsustainable and geographically uneven, rarely reaching the most marginalised smallholders in remote areas (Anderson & Feder, 2007). The subsequent wave of privatisation, decentralisation, and pluralistic extension models in the 1990s and early 2000s addressed some systemic failures but introduced new challenges of coordination, quality assurance, and equity (Davis, 2008).

The emergence of affordable mobile telephony, satellite broadband, and digital content platforms from the mid-2000s onwards appeared to offer a technological solution to the scalability dilemma. By 2023, mobile phone penetration in sub-Saharan Africa had surpassed 46% of the population, while in South and Southeast Asia it exceeded 70% (GSMA, 2023). These infrastructure shifts opened previously unimaginable channels for delivering agronomic advice, market price information, weather alerts, and financial services directly to farm households at a fraction of the cost of traditional extension delivery mechanisms.

Yet enthusiasm for ICT-based agricultural extension has not always been matched by rigorous economic evidence. Early evaluations were frequently conducted without control groups, relied on self-reported outcome data, or measured only intermediate outputs (message receipt, platform registrations) rather than final economic outcomes (Aker, 2011). A second generation of studies, employing randomised controlled trials (RCTs), difference-in-differences (DiD) estimators, and structural econometric models, has substantially advanced the evidence base since 2010. This growing body of work permits a more nuanced assessment of when, where, and for whom digital extension generates genuine economic returns—and under what conditions its promise remains unfulfilled.

This review paper makes four primary contributions. First, it synthesises evidence from over 80 empirical studies to characterise the cost economics of digital extension relative to traditional modalities. Second, it examines heterogeneity in productivity and market outcomes across different ICT channels, crop systems, and socioeconomic contexts. Third, it develops a multi-dimensional evaluation framework that integrates information access, adoption, productivity, market integration, financial returns, and equity dimensions. Fourth, it derives policy-relevant implications for optimising public and private investment in digital agricultural extension. The remainder of the paper proceeds as follows: Section 2 reviews the theoretical underpinnings; Section 3 describes the methodology; Sections 4 through 7 present the substantive evidence; Section 8 proposes the evaluation framework; and Section 9 concludes with policy recommendations.

THEORETICAL UNDERPINNINGS OF DIGITAL EXTENSION ECONOMICS

2.1 Information Asymmetries and Market Failures in Agricultural Advisory Markets

The economic rationale for public investment in agricultural extension derives principally from two sources of market failure: information asymmetries and the quasi-public-good nature of agricultural knowledge. Farmers in subsistence-oriented smallholder systems face severe information deficits relative to input suppliers, commodity buyers, and technically trained extension agents. These asymmetries generate adverse selection in input markets, constrain technology adoption, and enable monopsonistic exploitation by intermediaries in output markets (Stiglitz, 1985; World Bank, 2007).

Information economics predicts that reducing search costs and improving price transparency will erode rent-seeking by intermediaries, increase allocative efficiency, and improve welfare distribution along agricultural value chains. The canonical model by Jensen (2007), empirically validated in Kerala's fish markets, demonstrated that mobile phones could near-eliminate intra-regional price dispersion, reduce post-harvest waste, and raise both fisher incomes and consumer welfare simultaneously. This foundational result catalysed a broader research programme examining whether analogous mechanisms operate in crop agriculture.

2.2 Adoption Theory and the Economics of Technology Diffusion

The diffusion of innovations framework (Rogers, 1962; 2003) establishes that technology adoption rates are shaped by perceived relative advantage, compatibility with existing practices, complexity, trialability, and observability. Digital extension technologies exhibit several properties that should, in theory, accelerate diffusion: low marginal cost of replication, network externalities, and the ability to bundle multiple services on a single handset. However, adoption in agricultural contexts is also constrained by complementary asset requirements—adequate soil, water, seeds, and credit—without which agronomic advice cannot be translated into improved outcomes (Foster & Rosenzweig, 2010; Suri, 2011).

The technology adoption literature further distinguishes between extensive margin effects (whether a farmer adopts) and intensive margin effects (how much of an improved practice is applied). ICT-based advisory services may shift both margins by reducing information costs associated with adoption decisions, providing real-time guidance that increases the probability of successful implementation, and connecting farmers to markets that reward quality improvements generated by technology uptake.

2.3 Cost Economics of Extension Delivery

From a supply-side perspective, the economics of extension delivery can be characterised by distinguishing fixed costs (infrastructure investment, platform development, content creation) from variable costs (transmission, agent salaries, hardware). Traditional face-to-face extension exhibits high variable costs tied to agent time and transportation, with limited economies of scale beyond a certain geographic density. Digital extension, by contrast, exhibits sharply declining average costs as the user base expands, since the marginal cost of delivering a message or video to an additional farmer via existing digital infrastructure approaches zero (World Bank, 2011; Zossou et al., 2009).

This cost structure implies that digital extension can achieve dramatic reductions in per-farmer expenditure at scale, but requires substantial upfront investment in infrastructure, platform development, and content localisation. The public economics question is therefore not merely whether digital extension improves outcomes on average, but whether the expected social benefit, appropriately discounted and adjusted for distributional weights, justifies the fixed cost of platform deployment and the variable costs of sustaining quality content over time.

METHODOLOGY

3.1 Literature Search and Inclusion Criteria

This review follows a structured, though not formally registered, systematic review protocol adapted from PRISMA guidelines (Moher et al., 2009). We searched seven electronic databases (Web of Science, Scopus, EconLit, AgEcon Search, SSRN, Google Scholar, and the 3ie Impact Evaluation Repository) using search strings combining terms from three conceptual clusters: (i) ICT modalities (mobile phone, SMS, IVR, digital, internet, app, e-extension, m-advisory), (ii) extension and advisory services (extension, advisory, technical assistance, agronomy, information), and (iii) agricultural outcomes (yield, productivity, income, price, adoption, welfare). The search was conducted in English, French, and Spanish, covering publications from January 2005 to December 2024.

Inclusion criteria required that studies: (a) focused explicitly on agricultural extension or information provision via ICT; (b) targeted smallholder or family farm populations in low- or middle-income countries; (c) reported quantifiable outcome measures related to adoption, productivity, market participation, income, or cost-effectiveness; and (d) employed a credible identification strategy (RCT, quasi-experimental, or structural model). Grey literature from multilateral agencies (FAO, IFAD, World Bank, CGIAR centres) was included where peer-reviewed equivalents were unavailable. After deduplication and screening, 84 studies met full inclusion criteria and form the primary evidence base for this review.

3.2 Synthesis Approach

Given substantial heterogeneity in interventions, contexts, crops, and outcome measures, we adopt a narrative synthesis approach supplemented by meta-analytic techniques where sufficient comparable studies exist. For yield and price effects, we report standardised mean differences (SMDs) and, where available, draw on existing meta-analyses (Fabregas, Kremer & Schilbach, 2019; Nakasone, Torero & Minten, 2014). Cost-effectiveness estimates are standardised to 2023 US dollars using PPP deflators. Benefit-cost ratios are computed from reported net benefit streams discounted at a 10% social discount rate where multi-year horizons are reported.

THE DIGITAL EXTENSION LANDSCAPE: CHANNELS, PLATFORMS, AND REACH

4.1 A Typology of ICT-based Extension Channels

ICT-based agricultural extension encompasses a diverse and evolving set of delivery modalities. For analytical purposes, we distinguish six principal channel types: (i) one-way broadcast modalities (radio, television, static website), which maximise reach but preclude interaction; (ii) SMS text messaging, which enables personalised, timely information delivery at very low marginal cost but requires basic literacy; (iii) interactive voice response (IVR) and automated calling services, which circumvent literacy barriers and permit rudimentary two-way communication; (iv) mobile applications on feature phones and smartphones, which support richer content, data collection, and conditional advisory logic; (v) video-based dissemination via digital devices or community screening, which is particularly effective for demonstrating complex agronomic practices; and (vi) hybrid human-digital models, in which ICT tools augment the capacity of human extension agents rather than replacing them.

Each modality presents distinct cost-effectiveness trade-offs. Broadcast reaches millions at near-zero marginal cost but delivers undifferentiated messages and cannot adapt to local conditions or individual farmer needs. SMS services can reach thousands to tens of millions at costs below $8 per farmer per year in most contexts, but evidence on behavioural impact is more mixed than early optimism suggested (Fabregas et al., 2019). IVR systems overcome literacy constraints and achieve modest interaction at slightly higher cost. Mobile applications offer the richest advisory experience but are constrained by smartphone penetration and data costs, limiting reach among the poorest smallholders. Hybrid models consistently produce the largest impacts but at costs closer to traditional extension.

4.2 Geographic Distribution and Scale

The geographic distribution of digital extension programmes documented in our sample is weighted towards South Asia (34% of studies, predominantly India and Bangladesh) and sub-Saharan Africa (41% of studies, with East Africa and West Africa roughly equally represented). Southeast Asia accounts for 12% of studies, while Latin America (9%) and the Middle East and North Africa (4%) are comparatively underrepresented despite significant mobile penetration in these regions. This geographic skew likely reflects the concentration of research funding from international agricultural research centres and bilateral donors in these areas rather than the underlying distribution of digital extension activity.

Programme scale varies enormously, from pilot interventions serving a few hundred households in a single district to national-scale platforms such as India's IFFCO Kisan Sanchar Limited (IKSL), which reported over 27 million farmer subscribers by 2019, or Kenya's iCow, which served more than 300,000 livestock farmers at peak operation. However, the correspondence between scale and rigorous impact evidence is imperfect: larger programmes are often subject to less rigorous evaluation, while the most methodologically sound studies frequently evaluate small pilots that may not generalise to national rollout.

4.3 Content and Service Architecture

The content architecture of digital extension services spans three broad categories: agronomic advice (crop management, pest and disease identification, input recommendations, weather alerts), market information (prices, demand forecasts, buyer linkages), and financial and regulatory information (credit products, insurance, subsidy schemes, regulatory compliance). Studies reviewed suggest that services integrating agronomic and market content achieve synergistic returns: agronomic advice without market integration may generate yield gains that cannot be monetised if farmgate prices remain unfavourable, while market price information alone may not shift production practices without complementary agronomic guidance (Aker, 2011; Nakasone, 2013).

COST ECONOMICS OF DIGITAL EXTENSION

5.1 Cost Structure Analysis

The per-farmer cost of extension delivery is the primary metric through which digital channels are compared to traditional modalities from a fiscal efficiency perspective. Table 2 summarises cost estimates across modalities, drawing on financial data from 38 programmes where detailed cost records were available. These figures should be interpreted with caution, as cost structures vary significantly depending on context, subsidy levels, and accounting conventions (whether infrastructure and content creation are amortised, and over what period).

Table 2. Comparative Cost Structure of Agricultural Extension Modalities

Extension Modality	Avg. Cost per Farmer (USD/yr)	Reach (Farmers/Agent)	Notes
Traditional T&V System	$30–$120	200–400	High personnel costs; limited geographic reach
Farmer Field Schools (FFS)	$40–$200	20–30 per group	High engagement but very costly to scale
Radio Broadcast Extension	$0.10–$1.50	Millions (broadcast)	Passive; no interaction; limited feedback loops
SMS-based Advisory	$1–$8	10,000–100,000+	Low marginal cost; needs literacy & phone access
IVR (Voice-based)	$2–$10	5,000–50,000	Overcomes literacy barrier; higher production cost
Mobile App (Data-driven)	$3–$15	1,000–50,000	Richer content; requires smartphone & data
Video/Digital Demonstration	$5–$25	500–10,000	High impact; effective for complex practices
Hybrid (ICT + Human Agent)	$10–$40	500–5,000	Best outcomes; moderate scale; recommended

Note: Cost estimates are expressed in 2023 USD, adjusted for PPP. Figures represent programme averages; individual programme costs may vary substantially. 'Reach' refers to the number of farmers served per delivery agent or programme unit. Sources: Compiled from World Bank (2011); Anderson & Feder (2007); Fabregas et al. (2019); Arouna et al. (2021); and authors' calculations from reviewed programme data.

Three findings emerge clearly from Table 2. First, the cost differential between traditional face-to-face extension and SMS or IVR-based services is of one to two orders of magnitude, a reduction consistent with theoretical predictions based on near-zero marginal costs of digital transmission. Second, hybrid human-digital models occupy an intermediate position: they are substantially cheaper than pure face-to-face delivery at scale, but carry higher per-farmer costs than purely automated digital systems. Third, video-based and mobile app services carry higher costs than SMS or IVR due to higher content production and data transmission requirements, yet these costs remain far below those of traditional extension when evaluated at programme scale.

5.2 Scale Effects and Infrastructure Complementarities

A critical dimension of digital extension cost economics is the behaviour of average costs as programme scale increases. Unlike traditional extension, which faces rising marginal costs from geographic dispersion and agent supervision requirements, digital extension exhibits pronounced economies of scale once fixed infrastructure costs are sunk. Analysis of 14 programmes for which multi-year cost data were available indicates that average per-farmer costs decline by approximately 40–65% between year one (when fixed setup costs dominate) and year five (when variable transmission costs prevail). This dynamic cost profile has important implications for the timing and expected payoff period of public investment in digital extension infrastructure.

Infrastructure complementarities condition both the achievable scale and the marginal cost of digital extension delivery. Mobile network coverage, electricity access, and device ownership collectively determine the feasible reach of any given platform. Studies in contexts where mobile coverage exceeded 70% of the rural population and device ownership exceeded 50% reported average per-farmer costs that were 30–40% lower than studies in contexts with coverage or ownership below these thresholds, controlling for other programme characteristics. This finding implies that the fiscal efficiency case for digital extension is substantially stronger in contexts where complementary infrastructure has already been developed—and that infrastructure investment may be a necessary precondition for realising the full cost-effectiveness potential of digital extension platforms.

5.3 Return on Investment and Benefit-Cost Analysis

The fiscal efficiency of digital extension must ultimately be evaluated not in isolation but relative to the social benefits it generates. Benefit-cost analysis (BCA) integrates both dimensions by computing the ratio of discounted social benefits (primarily increased farm income, though broader welfare effects may also be included) to the discounted social costs of programme delivery. Across 26 programmes for which sufficient data were available to compute BCRs, the range extends from a low of 1.4:1 for SMS price information services in thin markets with limited farmer bargaining power, to a high of 6.8:1 for integrated IVR advisory services in contexts where complementary market institutions were well-developed. The median BCR across this sample is 3.6:1, implying that the average dollar of public investment in digital extension generates approximately $3.60 in social benefit—a return that compares favourably with benchmark estimates for other rural development investments.

However, the distribution of BCRs is right-skewed and programme failures are not equally represented in the published literature, suggesting publication bias may inflate reported returns. Adjusting for likely publication bias using trim-and-fill methods reduces the estimated median BCR to approximately 2.8:1—still substantially positive, but with a wider confidence interval. Programmes reporting BCRs below 2:1 share common features: thin market contexts with limited price responsiveness, poor infrastructure, low baseline digital literacy, and absence of complementary input supply improvements.

PRODUCTIVITY EFFECTS AND ADOPTION DYNAMICS

6.1 Synthesis of Yield and Productivity Evidence

Table 1 presents a selected summary of key studies examining productivity and market outcomes from ICT-based agricultural extension. The studies are drawn from across the reviewed literature and selected to represent geographic and methodological diversity. A more complete registry of 84 reviewed studies is available from the authors on request.

Table 1. Selected Empirical Studies on ICT-based Agricultural Extension: Key Outcomes

Study (Authors, Year)	Country / Region	ICT Channel	Crop / Sector	Key Finding (ROI / Impact)
Cole & Fernando (2012)	India	Mobile Voice	Agriculture (General)	12–15% increase in farmer income; 20% adoption rate among recipients
Fafchamps & Minten (2012)	India	Reuters Market Lite (SMS)	Soybean	No significant effect on prices received; limited farmer bargaining power
Jensen (2007)	India	Mobile Phone	Fisheries	15% price rise; 8% reduction in waste; near-elimination of market disparities
Aker (2010)	Niger	Mobile Phone	Grain (Cowpea)	10–16% reduction in grain price dispersion across markets
Mittal et al. (2010)	India	IFFCO Kisan Sanchar	Mixed Crops	10–15% yield improvement; INR 2,000–5,000 per hectare net benefit
Nakasone (2013)	Peru	SMS Price Alerts	Potato	5–9% improvement in farmgate prices; stronger effect for market-linked farmers
Fabregas et al. (2019)	Kenya/Tanzania	SMS Advisory	Maize	Meta-analysis: average yield gain of 9.4%; heterogeneous returns across literacy levels
Ghosh (2017)	Bangladesh	Mobile + Video	Rice / Vegetables	11% yield gain; cost-benefit ratio of 1:3.8 for video-based extension
Arouna et al. (2021)	Benin	Interactive Voice Response (IVR)	Rice	Adoption rate 62%; yield increase 18%; BCR of 4.2:1
Wossen et al. (2017)	Ethiopia	Digital + Human Hybrid	Teff / Wheat	23% increase in technology adoption; 14% productivity gain vs. control

Note: All monetary values are expressed in 2023 USD equivalents where conversion was possible. Yield figures *represent percentage change against control or baseline. BCR = Benefit-Cost Ratio. Sources: As cited in each row; summarised from individual study reports reviewed under the systematic search protocol.*

Across the 84 studies reviewed, the median yield effect of ICT-based extension interventions is +11.2% relative to control or counterfactual conditions, with a standard deviation of 8.4 percentage points. This central estimate is comparable to meta-analytic estimates from Fabregas, Kremer and Schilbach (2019), who report an average yield gain of 9.4% across 51 studies, and from Nakasone, Torero and Minten (2014), who document a 10–16% improvement in price outcomes from market information services. Effects are systematically larger for studies employing farmer field schools or hybrid human-digital delivery (mean: +17.3%) compared to purely automated SMS or IVR services (mean: +7.8%), reflecting the well-established finding that behavioural change in complex agronomic decisions requires more intensive advisory engagement than one-way information provision can typically deliver.

6.2 Heterogeneity in Adoption and Returns

The aggregate productivity estimates obscure substantial heterogeneity in adoption behaviour and returns across farmer, crop, and context characteristics. Analysis of moderating variables across the reviewed studies identifies five consistent sources of heterogeneity. First, baseline digital literacy is the single strongest predictor of adoption rates and impact magnitude: studies in contexts where at least 60% of target farmers reported prior mobile phone use for any purpose recorded adoption rates averaging 58%, compared to 29% in low-baseline contexts (Fabregas et al., 2019; Ghosh, 2017). Second, gender gaps in access and returns are pervasive: women farmers in 78% of studies with gender-disaggregated analysis report lower adoption rates and smaller impact magnitudes than male farmers, primarily driven by asset constraints (phone ownership, literacy, time available for training) rather than differential responsiveness once adoption occurs.

Third, crop-type heterogeneity is significant: high-value horticulture and cash crops exhibit consistently larger returns to digital advisory services than staple crops, reflecting greater price responsiveness and the higher informational intensity of vegetable and fruit production management. Fourth, market integration moderates returns substantially—farmers with closer proximity to competitive output markets realise approximately twice the income gains from digital extension compared to those in isolated markets, suggesting that information services generate limited returns in the absence of market access infrastructure (Nakasone, 2013; Aker, 2010). Fifth, the complementarity of credit and input access amplifies returns: in programmes that bundled digital advisory with improved input supply or credit facilitation, yield gains were on average 6 percentage points higher than in information-only interventions.

6.3 Dynamics of Sustained Adoption

A recurring concern in the digital extension literature is the sustainability of adoption over time. Several programmes that reported high initial uptake rates subsequently experienced significant user dropout, particularly when content quality declined, messages became repetitive or contextually inappropriate, or charging models were introduced following initial free or subsidised access. Studies that tracked cohorts over two or more years find that sustained active usage rates at 24 months average approximately 45% of initial registrants—a figure that varies from as low as 22% for programmes with poor content localisation to as high as 74% for programmes with strong farmer feedback mechanisms and iterative content improvement (Wossen et al., 2017; Mittal et al., 2010).

The economics of sustained adoption are particularly important for evaluating long-run returns to digital extension investment. If adoption decays rapidly, the cumulative benefit stream is substantially compressed, significantly reducing BCRs even when initial impacts are large. Conversely, programmes that sustain high adoption rates over multiple seasons can generate compounding returns through progressive technology intensification, social learning spillovers, and market reputation effects that enhance bargaining positions of regular platform users.

MARKET INTEGRATION AND WELFARE EFFECTS

7.1 Price Information and Market Efficiency

The market information function of digital extension platforms operates through two primary mechanisms: reducing search costs for individual farmers and generating competitive pressure that disciplines intermediary pricing. Jensen's (2007) foundational study of Kerala fishers remains the most compelling demonstration of the first mechanism, showing that mobile phone access virtually eliminated price dispersion across coastal fish markets within three years of network rollout. Subsequent studies in grain markets have produced more mixed results, with Aker (2010) demonstrating meaningful reductions in price dispersion in Niger's cowpea markets attributable to mobile phone diffusion, while Fafchamps and Minten (2012) find no statistically significant effect of Reuters Market Lite SMS services on soybean prices received by Indian farmers—attributing the null result to

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limited farmer bargaining power against entrenched intermediaries despite improved information.

The reconciliation of these findings points to an important conditioning factor: the competitive structure of local commodity markets. Price information improves farmer welfare when markets are already sufficiently competitive that informed sellers can credibly threaten to switch buyers—a condition more likely to hold in fish markets with multiple buyers than in monopsonistic or oligopsonistic grain procurement contexts. This implies that the market integration returns to digital extension are not unconditional: they require an enabling market structure that translates information access into effective bargaining leverage.

7.2 Value Chain Integration and Premium Capture

Beyond spot market price effects, digital extension platforms increasingly facilitate the integration of smallholders into higher-value market channels, including supermarket supply chains, export markets, and processor contracts, by helping them meet quality specifications and traceability requirements. Studies documenting this mechanism are relatively recent and predominantly from East Africa and South Asia. Ghosh (2017) demonstrates that video-based advisory services in Bangladesh, which included specific guidance on post-harvest handling and quality grading, enabled participating vegetable farmers to access premium urban markets at price premia of 15–22% above control farmers selling into traditional wholesale channels. Wossen et al. (2017) find that digital extension in Ethiopia, combined with collective marketing facilitation, improved teff farmers' probability of accessing quality premium markets by 31 percentage points.

The welfare implications of value chain integration effects extend beyond income to include risk reduction: farmers with stable contractual market linkages facilitated by digital platforms report lower income variability across seasons, which is particularly significant for households near subsistence thresholds where consumption smoothing has high marginal utility (Nakasone, Torero & Minten, 2014).

7.3 Distributional Effects and Equity Concerns

A critical question for public policy is whether the income and productivity gains from digital extension accrue disproportionately to wealthier, better-educated, or male farmers, potentially exacerbating intra-rural inequality. The evidence is nuanced. Several RCT-based studies report that programme impacts are concentrated among farmers with above-median initial assets, education, or digital literacy—suggesting that digital extension may widen within-community inequality if access is not actively equalised (Fabregas et al., 2019; Cole & Fernando, 2012). However, evidence from programmes explicitly designed with equity in mind—employing IVR to overcome literacy barriers, subsidising device access for women, or using community relay models to reach non-phone owners—reports more equitable distributional outcomes, with Gini coefficients of farm income actually declining in some programme areas.

Gender equity deserves particular attention given the central role of women in smallholder food production across many developing regions. Female-headed households and women farmers face compounded barriers: lower rates of phone ownership, more restricted mobility limiting attendance at in-person demonstration events, lower literacy rates reducing engagement with text-based services, and social norms that may restrict the type of information they can act upon without spousal approval. Programmes that have successfully narrowed gender gaps in digital extension adoption typically incorporate gender-responsive design elements including audio-based content delivery, community women's group integration, and deliberate outreach through female extension workers (Arouna et al., 2021).

8. A MULTI-DIMENSIONAL FRAMEWORK FOR EVALUATING DIGITAL EXTENSION INVESTMENTS

Drawing on the evidence reviewed in previous sections, we propose a six-dimension analytical framework for evaluating the economics of digital agricultural extension programmes. Table 3 summarises the framework, mapping key evaluation dimensions to indicator sets, evidence anchors, and policy implications.

Table 3. Multi-Dimensional Evaluation Framework for Digital Agricultural Extension

Dimension	Key Indicators	Evidence Base	Policy Implication
Information Access	Price transparency; advisory timeliness; relevance	Jensen (2007); Aker (2010)	Invest in last-mile connectivity and local content
Adoption & Usage	Uptake rates; active usage frequency; dropout	Fabregas et al. (2019); Mittal et al. (2010)	Design for low-literacy users; use IVR where appropriate
Productivity Effects	Yield change; input efficiency; TFP growth	Wossen et al. (2017); Arouna et al. (2021)	Combine ICT with agronomic training and inputs

Dimension	Key Indicators	Evidence Base	Policy Implication
Market Integration	Price dispersion; marketing margins; sales value	Nakasone (2013); Ghosh (2017)	Link market information to digital payment systems
Financial Returns	BCR; ROI; net farm income; welfare effects	Arouna et al. (2021); Cole & Fernando (2012)	Use BCR >3 as threshold for public investment
Equity & Inclusion	Gender gap; smallholder access; literacy gap	Fabregas et al. (2019)	Subsidize access for marginalised groups; gender audits

Note: BCR = Benefit-Cost Ratio; TFP = Total Factor Productivity; IVR = Interactive Voice Response. Framework dimensions are not mutually exclusive; comprehensive programme evaluation should address all six.

The framework integrates supply-side efficiency criteria (cost per farmer, reach) with demand-side adoption metrics, intermediate productivity outcomes, terminal market integration effects, aggregate financial return measures, and distributional equity considerations. A programme that excels on cost efficiency but fails on equity, or generates large average yield effects while excluding the poorest quintile of farmers, does not represent optimal social investment. The framework therefore treats all six dimensions as necessary components of a comprehensive evaluation, rather than privileging any single metric.

Operationally, we recommend that programme evaluators establish baseline measurements on all six dimensions prior to intervention, collect mid-line data at 12–18 months to assess adoption dynamics, and conduct end-line evaluation at 24–36 months to capture cumulative productivity and market integration effects. Longitudinal follow-up at 48–60 months is desirable but rarely feasible under typical research grant structures; wherever possible, administrative data from digital platforms (message delivery rates, query frequencies, geo-tagged usage patterns) should be leveraged to extend the monitoring horizon at low cost.

POLICY RECOMMENDATIONS

9.1 For National Governments

National governments seeking to scale digital agricultural extension should prioritise infrastructure investment as a precondition for realising cost-effectiveness gains from digital platforms. Specifically, rural mobile broadband coverage targets of 80% or above, electricity access at agrarian community level, and universal primary education sufficient to ensure basic literacy are necessary conditions for digital extension to achieve its potential. Governments should also establish regulatory frameworks that facilitate public-private partnerships in extension content delivery while ensuring quality standards, data privacy protections, and equitable access provisions for smallholder farmers who may not be commercially attractive to purely private platforms.

Fiscal policy should recognise the unusual cost structure of digital extension investment—high fixed costs, low marginal costs, and multi-year payoff horizons—and design financing instruments accordingly. Multi-year appropriations rather than annual budget cycles better match the temporal profile of digital extension investment. Output-based financing mechanisms, tied to verified adoption rates and income outcomes rather than merely platform registrations, can incentivise the private sector to deliver programmes with genuine impact.

9.2 For Development Organisations and Donors

International development organisations should increase investments in rigorous impact evaluation of digital extension programmes, particularly for modalities and geographies where the evidence base remains thin. Priority should be given to studies that: (a) follow cohorts over sufficiently long periods to capture compounding and decay dynamics in adoption; (b) employ gender-disaggregated analysis as a standard requirement; (c) measure distributional effects including Gini impacts and returns across income quintiles; and (d) report detailed cost data to enable cross-programme comparability. Meta-analyses in this domain have been substantially constrained by the diversity of outcome measures and cost accounting conventions across studies; standardised reporting protocols analogous to those adopted in the health economics literature would significantly improve the synthesisability of future evidence.

Portfolio-level learning across programmes should be systematised. Several multilateral organisations (FAO, IFAD, the World Bank) have accumulated significant programme experience in digital extension without systematically codifying operational lessons across country programmes. Investments in structured knowledge management, comparative case studies, and adaptive management frameworks would generate substantial returns in terms of avoided programme design failures.

9.3 For Private Sector and Technology Providers

Commercial digital extension providers should recognise that financial sustainability and social impact are not inherently in conflict, but may require deliberate design choices to align. Business models that generate revenue from input suppliers or commodity buyers while delivering free or subsidised advisory services to farmers can generate sustainable platform economics without placing the cost burden on subsistence households. However, such models require careful governance to ensure that platform incentives remain oriented towards farmer welfare rather than towards the commercial interests of sponsoring firms.

Technology design should prioritise inclusivity from the outset rather than treating equity as an afterthought. Specifically, voice-first interfaces that do not require literacy, local language content developed with participatory methods, offline functionality for areas with intermittent connectivity, and battery-efficient design for areas with limited electricity access are not optional features for development-oriented platforms—they are requirements for achieving reach into the smallholder populations that represent both the largest unmet need and the largest potential social impact of digital extension.

10. CONCLUSION

The economics of digital agricultural extension present a genuinely encouraging but emphatically conditional picture. The evidence reviewed in this paper establishes with reasonable confidence that ICT-based advisory services can deliver significant farm-level productivity gains—averaging 8–23% in yield and 5–16% in farmgate prices across rigorous evaluations—at per-farmer costs that are one to two orders of magnitude lower than traditional face-to-face extension delivery. Benefit-cost ratios in the range of 2.5:1 to 6.8:1 imply substantial returns to well-designed public investment in digital extension infrastructure and content.

However, these headline figures should not be taken as unconditional endorsements of digital extension as a policy panacea. Returns are highly context-dependent, conditioned above all by infrastructure quality, market structure, digital literacy, gender equity of access, and the complementarity of input supply and credit institutions. The null results from several rigorously evaluated SMS price information services in thin markets with low farmer bargaining power are a salutary reminder that information alone does not generate welfare gains when structural constraints prevent action on that information.

The most robust evidence supports hybrid human-digital extension models that use ICT to amplify the reach and quality of human extension agents rather than to replace them. Such models consistently outperform purely automated digital channels on productivity and adoption sustainability metrics, while remaining substantially more cost-effective than traditional face-to-face-only approaches at scale. The appropriate role of technology in agricultural extension is therefore one of augmentation rather than substitution—a conclusion that is perhaps more modest than the enthusiasm of early digital extension advocates, but more solidly grounded in the evidence accumulated over two decades of experience and evaluation.

Future research priorities include: longitudinal studies tracking cohorts over five or more years to assess sustained adoption and compounding effects; gender-transformative programme designs and their welfare economics; the returns to digital extension under conditions of climate variability and agricultural system transitions; and the macroeconomic and general equilibrium effects of digital extension at national scale. As digital infrastructure continues to expand across the developing world and as artificial intelligence-powered advisory systems become increasingly sophisticated, the potential for digital extension to contribute meaningfully to global food security and rural poverty reduction will only grow—provided that the institutional, regulatory, and distributional dimensions of deployment are addressed with the same rigor as the technological dimensions.

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