A New Methodology for Estimating Costs and Benefits of Climate Information Services (CIS) among Smallholder Farmers

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About AICCRA

Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) is a project that helps deliver a climate-smart African future driven by science and innovation in agriculture. It is led by the Alliance of Bioversity International and CIAT and supported by a grant from the International Development Association (IDA) of the World Bank.

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Abstract
One of the main objectives of the Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) program is to facilitate the development and evaluation of tailored climate information services (CIS) for smallholder farmers across SSA. To provide an economic justification for investing in CIS, this briefing note introduces the building blocks of a toolkit to determine costs and benefits of CIS. Understanding these costs and benefits will help design and scale-up economically viable CIS packages and determining the impacts of CIS on smallholder farmers' livelihoods. Existing cost-benefit analysis methods tend to quantify the net present value (NPV) of future cash flows, which neglects benefits that are not directly valued in monetary terms such as more stable incomes, improved consumption smoothing when exposed to climate shocks, changes in time use, and the intra-household distribution of the costs and benefits. We present an expected utility framework to quantify and aggregate such benefits for more comprehensive cost-benefit analyses of CIS packages. The toolkit is still a work in progress and the authors welcome feedback and comments from readers and potential users.

Keywords
Climate information services; Gender; Cost-benefit analysis; Agriculture, Sub-Saharan Africa.

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1. Introduction

The Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) is a World Bank funded initiative that aims to support the development and scaling of the most strategic and impactful climate change mitigation strategies across Africa. One of the main objectives of AICCRA is to facilitate the development and evaluation of tailored climate information services (CIS) packages for small-scale farmers in the target countries. Given that farmers and other stakeholders operate on limited resources, it is important to provide an economic justification of providing the interventions and farmer adoption of the CIS technologies.

Understanding the costs and benefits of implementing CIS has a number of benefits at the policy and individual level. First, understanding the private and public costs of providing CIS versus the benefits that these packages offer to users is crucial in informing decision-makers on the potential cost-effectiveness and returns associated with different CIS packages, and thereby helping them prioritize investments and in scaling-up relevant packages. Second, understanding the heterogeneous dimensions (such as the gender dynamics) of the costs and benefits of CIS will be important in targeting the most cost-effective technologies to different farmers based on farm typologies, and demographic characteristics. For instance, gender-responsive CIS requires tailoring packages that accommodate women's domestic roles and constraints that can limit access and their ability to benefit from conventional CIS technologies. Third, understanding the cost-effectiveness of CIS can help in determining its impacts in terms of a time of return and livelihood levels achieved and maintained in the short- and long-term (Daigneault et al., 2016). Finally, a cost-benefit analysis presents a business opportunity pending sufficient analysis of related trade-offs (Schroth et al. 2015).

This briefing note provides a guide to quantify the cost and benefits of providing CIS packages to farmers. The document is part of a cost-benefit analysis toolkit developed by the International Food Policy and Research Institute (IFPRI) in collaboration with the International Research Institute for Climate and Society (IRRI), and in consultation with AICCRA country teams[1]. By employing this tool, users will be able to answer the following questions:

1) What are the costs and benefits of providing CIS packages to small-scale farmers?

[1] Initial documentation on stakeholder engagement can be found at https://cgspace.cgiar.org/handle/10568/117796 and https://cgspace.cgiar.org/handle/10568/117684

2) Are there gender-based differences in the distribution of these costs and benefits?
3) How do findings vary with types of CIS packages and on distribution channels?

The remainder of this note is structured as follows. Section two provides a simple conceptual framework highlighting the properties of various CIS packages available to farmers in SSA and their implications on costs and benefits. Section two also provides brief literature of the previous cost and benefit analyses, and the contribution of the toolkit toward the existing literature. Section three provides the theoretical approaches used in estimating the costs and benefits of CIS. Section four provides the conclusion and next steps.

2. Materials and Methods

2.1 Climate Information Services

CIS involves the collection, organization, packaging, tailoring, and distribution of targeted, tailored, and timely weather and climate information, such as rainfall, temperature, wind, and soil conditions among others (Tall, et al. 2014). CIS has several desirable attributes that make it attractive to many smallholder farmers; given that CIS provides knowledge of weather conditions based on both present and past years' occurrences, the information provided can be reliable at different timescales for proper climate model simulation and planning at the farm level (Asrar et al., 2012). CIS can operate on an interactive mechanism between the providers and end-users to identify needs and services and hence information can be tailored to a given demographic or farm typology (Tall et al., 2014). Given the heterogeneity in farm operations in SSA, the ability to deliver tailor-made services to users makes CIS an attractive climate adaptation and mitigation mechanism. Timeliness and accuracy in CIS delivery can enhance early planning, promote the use of other effective preventive measures, and improve rational farm production decisions, especially for poor households (Mishra et al., 2012; Nguyen et al. 2013).

To evaluate the costs and benefits of CIS, we develop a systematic framework to distinguish between four types of CIS that are available to farmers in SSA: Advisory services, meteorology and weather forecasts, participatory services, and indigenous knowledge. In Table 1, we indicate to what extent each of these types of CIS are accessible to smallholders, their scalability, timeliness, and accuracy of the information delivered, to what extent they can be tailored, the costs for farmers (that is, their end users) versus their providers, to what extent they are gender inclusive, the extent to which they provide actionable recommendations versus more passive information, and the channels through which the advisories are delivered to farmers.

Table 1: Type of CIS available to farmers in SSA

	Advisory services	**Meteorology and weather forecast (MWF)**	**Participatory services**	**Indigenous Knowledge (IK)**
Accessibility to smallholders	High	Medium	Low	Low to medium
Scalability	Low	High	Medium	Low
Timeliness	Low to medium	High	Low to medium	Low
Accuracy	Low to medium	High	Low to medium	Low to medium
Ability to tailor services	High	Low	High	Low
Costs to farmer	Low	Medium	Low	Low
Cost to providers	High	Medium	High	Low
Gender inclusivity	Medium	High	Low	Low to medium
Actionability	High	Low	High	Medium
Medium of delivery	Extension officers, farmer field days, call center, interactive voice messaging (IVR), NGO, newspaper/bulletin	Mobile phone applications, SMS, IVR, radio, television	Extension officers, farmer field days, NGO, newspaper/bulletin, farmer to farmer learning	Word of mouth

A first type of CIS comes in the form of advisory services. To deliver advisory services, CIS organizations can collect information about the climatic conditions of their beneficiaries' environment and send out information to farmers on how to protect their livelihoods from environmental shocks or what coping strategies to use in the aftermath of an environmental shock. An example of this type of CIS is the Kenya Climate Smart Agriculture Project (KCSAP), implemented by the Kenya Agricultural and Livestock Research Organization (KALRO) and the Kenya Meteorological Services. KCSAP provides farmers with agro-weather advisories through digital and in-person field visits. The agro-advisory information guides farmers in selecting promising climate-smart agricultural technologies, innovations, and management practices for their agro-ecological zones and priority value chains. Farmers also receive support for micro-projects that aim to increase incomes and diversify livelihood strategies and reduce their exposure to climate change-related risks (USAID, 2021). The main advantage of climate advisory programs is that farmers do not need to interpret the climate information themselves, but that it comes with actionable advice. In addition, the cost to the farmer is low, similar advisories can be applied to larger groups, and it permits the scaling up of CIS for homogenous regions/areas/communities (Carr et al., 2015; Carr and Onzere, 2018). However, this type of CIS can be costly to implement for their providers, and given its high top-down approach, it can be exclusive to some categories of farmers.

Meteorological and weather forecast (MWF) services are a form of CIS that concentrate on predicting weather conditions over time. This is done mostly in collaboration with the national meteorological agency of the host country. MWF services typically leverage the nation's data on climate and weather but also utilize climate and weather information available on both regional and global scales (Singh et al., 2018). The core of MWF is producing climate data rather than translating the data into usable services for smallholder farmers (Chiputwa et al., 2020), which is making them less actionable than advisory services. The costs of providing MWF services are therefore however lower than those of advisory services for the provider, but there are still significant costs involved. Compared to other types of CIS packages, the scientific methods employed can be considered desirable in terms of increased accuracy and timeliness in delivery.

Participatory CIS uses a multi-stakeholder approach to provide a holistic assessment of the interaction between climate, and the livelihood strategies pursued by the rural communities. Providers integrate data from meteorological and weather forecasts with those from surveys and encourage farmer participation to develop and disseminate actionable climate recommendations for the future (Tall et al. 2018). An example of participatory CIS is the Participatory Integrated Climate Services for Agriculture (PICSA) program implemented in several countries in Africa, Asia, and Latin America. PICSA involves agriculture extension staff working with groups of farmers ahead of the agricultural season to analyze historical climate information and use participatory tools to develop and choose livelihood options best suited to individual farmers' circumstances (Dayamba et al. 2018). The approach is desirable because it can foster inclusivity and ownership among beneficiaries, and information can be easily tailored to different geographical regions, farm typologies and demographics. The cost of participatory methods can however be high for the providers, and the service might be inaccessible to some farmers, especially women with limited physical mobility.

Indigenous knowledge, a final type of CIS, is based on a cumulative and complex body of knowledge, practices, and representations that are maintained and developed by people with extended histories of interactions with the natural environment (Rhodes et al. 2014). This type of CIS can be cheaper to provide and will also come with lower costs for farmers, but there are challenges involved with packaging and providing this information at a larger scale. Moreover, with increased penetration of improved digital and agricultural technologies, indigenous knowledge is expected to play an increasingly minor role in climate change adaptions in the future. Indigenous knowledge however needs to be documented and promoted as it can provide a crucial foundation for community-based adaptation and mitigation actions that sustain the resilience of local livelihoods and systems. Moreover, building CIS packages on indigenous knowledge can increase their acceptance among beneficiaries.

Each CIS type can be delivered through different channels that can have implications on the costs and benefits for the end-users and providers. For instance, word of mouth and farmer-to-farmer learning will have low-cost implications, while if a medium requires a subscription, the farmer will have to incur periodic payments. Other technologically advanced mediums such as television, radio, and mobile phones will have a high initial fixed cost of adoption, but the ongoing overhead costs will be borne by the providers. It might also be easier for women to access information provided via radio or a TV show in their homestead as opposed to an in-person farmer meeting because of their high work burdens, mobility constraints, and cultural barriers that require them to ask permission from other household members to participate in in-person meetings. The toolkit that we are developing will allow researchers to quantify these differential costs and benefits associated with the different CIS packages and distribution channels.

2.2 Cost-Benefit Analysis

As described in the previous section, different CIS and the subsequent delivery channels have varied benefits and cost implications for the providers and end-users. Direct benefits are benefits for which the product was created, for instance, CIS can directly benefit the farmer through increased farm productivity, food security, resilience to climate shocks, more efficient time use, and farm profitability. Indirect benefits accrue due to the target group applying the technology while benefits are realized by other non-targeted groups; for instance, increased food supply due to CIS can help in lowering food prices which can increase real incomes. On the other hand, CIS can have direct cost implications to the providers (such as mobile phone application development, cost of acquiring the data, and human resources, among others) and farmers (such as the cost of adoption). CIS costs can also be indirectly reflected in terms of expenditure on inputs or labor demand.

Based on Kramer and Ceballos (2018), Figure 1 provides an example of how CIS can benefit the farmer through increased agricultural payoffs. The agricultural payoffs depend on CIS use (γ) and the weather conditions (φ). The dashed line indicates payoffs under non-CIS production ($\gamma = 0$) while the solid line indicates payoffs under CIS ($\gamma = 1$). Under normal weather conditions, $\varphi \leq \varphi^0$ payoffs are at their maximum level, while moderate weather conditions, $\varphi \in (\varphi^0, \varphi^1)$ reduces payoffs under normal practices, but crops under CIS are more resilient and suffer only once weather conditions become more severe, $\varphi \in (\varphi^1, \varphi^2)$. In years with extreme weather conditions, $\varphi > \varphi^2$, payoffs tend to zero under both cropping systems. We will model the relationship between payoffs from agricultural activities, weather conditions and adoption of CISS in a similar way.

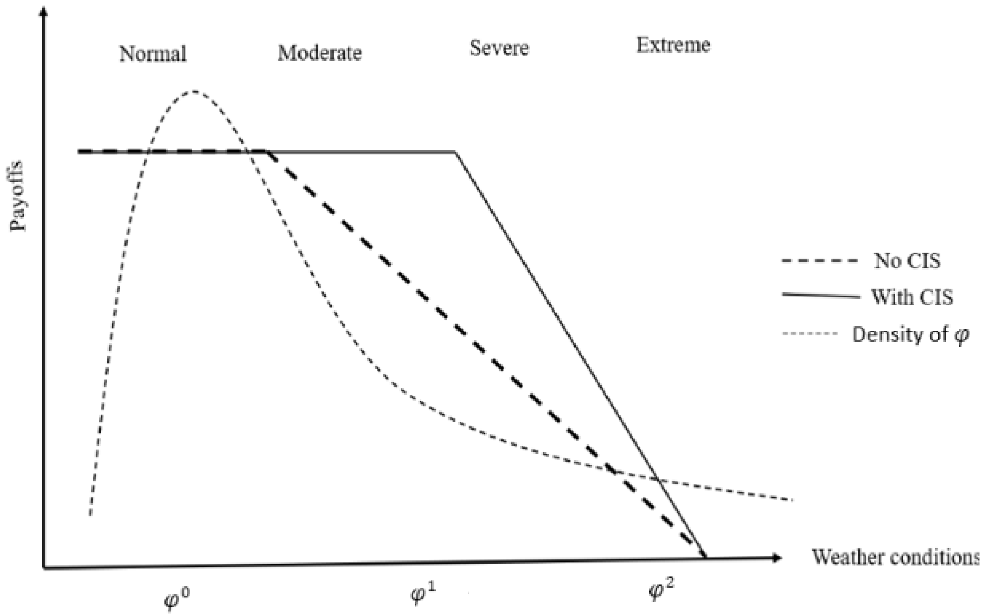

Figure 1; Density of Weather shocks and payoffs due to CIS (adapted from Kramer and Ceballos, 2018)

Previous climate-related cost-benefit analyses (such as Sain et al. 2017; Ng'ang'a et al., 2017a, 2017b; Williams et al. 2020) employ a net present value (NPV) approach, in which the present value of future expected net cash flows is aggregated across time periods. These studies comprehensively capture the expected value of direct costs and benefits associated with changes in incomes and farm profitability. At the same time, outcomes that are not directly valued in monetary terms but are important to farmers, for instance, improved consumption smoothing when exposed to climate shocks, or protection of assets from income losses associated with climate shocks, are ignored. This is because an expected NPV framework assumes that farmers are risk neutral, whilst benefits associated with improved risk coping will depend on a farmer's level of risk aversion. In addition, the intrahousehold distribution of costs and benefits is typically not captured under the conventional NPV approach. For instance, CIS recommendation to apply fertilizer may call for increased weeding and post-harvest processing, tasks often done by women, which can increase women's workload and thereby worsen time poverty, resulting in women's disempowerment. CIS might also promote male-centric production systems, crowding out women's incomes from agriculture. Our toolkit aims to capture a more complete picture of costs and benefits associated with CIS, including benefits from improved risk coping and intrahousehold dynamics.

3. Theoretical Framework

3.1 Expected Utility Framework

We propose using a dynamic utility model to quantify costs and benefits. The model acknowledges that while choosing their consumption, savings and labor allocations, farmers will not only look at their wellbeing in the current period, but also at how their current decisions affect asset accumulation and expected utility over a longer period of time. To capture the intrahousehold dynamics in the distribution of CIS costs and benefits, we model CIS adoption using a collective household model where each person has unique preferences over the allocation of family resources (Chiappori 1988, 1992). For simplicity, we use a two-person household and assume that over time T the individual k will maximize the following expected utility function,

$$\max_{C_{kt}, R_{kt}} EU = \sum_{t=0}^{T} \beta_k^t \emptyset_i U_i(C_{kt},\ R_{kt}\ ;\ \gamma_{tm}) \qquad (1),$$

where, in time t, individual $k \in \{1,2\}$ derives utility from consumption C and leisure R. Individual time preference is denoted by β_k and $\emptyset_t$, $i = 1, 2, 3$ is the probability of realizing different weather outcomes; that is, good, moderate, or severe weather conditions, respectively. $\gamma_{tm} \in \{0,1\}$, indicates whether the household has access to CIS package m in period t. The individual utility function $U(.)$ is continuous, increasing ($U' > 0$), twice differentiable and strictly concave ($U''(.) < 0$). We assume the utility function exhibits constant relative risk aversion (CRRA; $r > 0$).

The level of individual consumption and leisure over a time period t in state i is determined by the following budget and time constraints.

$$C_{ikt} = Y\left(l_{ikt}, A_{ikt}; \gamma_{jm}, \delta_{ikt}\right) + W_{ikt}(L_{ikt}) = M_{ikt} - \Delta s_t \qquad (2)$$

$$T = R_{ikt} + l_{ikt} + L_{ikt} \qquad (3),$$

where, Y_{ikt} represents income from agricultural production —a function of l_{ikt} (the individual's time allocation to farm work), and of A_{it} (the individual's investments in farm production, in state i during season t), whilst W_{ikt} represents the market labor wage, L_{ikt} is the individual $k's$ labor allocation to non-farm activities, M_{ikt} is the total income, and net savings or assets accumulated from the previous to the current period are represented by $\Delta s_t \equiv (1+r)s_{t-1} - s_t$. Thus, consumption needs to be equivalent to total income from farming and non-farm labor work, minus any savings that are being accumulated from the previous to the current period. The time constraint (Equation 3) states that in period t and state i, individual k has a time endowment T that is allocated to leisure (R), farm work (l), and waged off-farm work.

We model income from agricultural production as a function $Y(\cdot)$ of labor and investments allocated to the farm (l and A, respectively), conditional on the state of nature, $\emptyset_t \in \{1,2,3\}$, and whether the farmer has adapted its farming practices and technologies based on recommendations provided by CIS, with $\gamma = 1$ if the farmer is indeed following CIS-recommended practices. Following Figure 1, we assume that for a given level of labor and agricultural investment, income from agricultural production does not depend on whether a farmer adopts CIS-recommended practices in good or bad states of nature, but under moderate weather conditions, CIS-recommended practices shield agricultural payoffs from losses. Formally,

$$Y(\cdot\,;1{,}1) = Y(\cdot\,;0{,}1) < Y(\cdot\,;0{,}2) < Y(\cdot\,;1{,}2) < Y(\cdot\,;1{,}3) = Y(\cdot\,;0{,}3)$$

This is not to say that CIS packages can have an impact on agricultural incomes only under moderate weather conditions. Reduced exposure from moderate risks could crowd-in investments and on-farm labor in each state of the world, also under good and bad weather conditions, given that investment and labor decisions are typically made before one knows what type of season it will be. Through that channel, CIS packages can shift production outwards, and have an impact across all states of nature. To quantify these effects for different states of nature, programs will ideally generate empirical data on the impacts of CIS packages on consumption patterns, labor allocations, agricultural investments, and savings or asset accumulation in years with severe, moderate and good weather conditions.

The time constraint can be solved for L_{ikt} and substituted into equation (2) to obtain the individual full budget constraint such that:

$$M_{ikt} = Y\big(l_{ikt}, A_{ikt}; \gamma_{jm}, \delta_{ikt}\big) + (T - R_{ikt} - l_{ikt})\, W_{ikt} + \Delta s_t \quad (4)$$

The problem faced by an individual in time period t is identical to the problem faced in any other time period conditional on the state of the weather and assets saved in period $t-1$. For simplicity, a 10-year planning horizon is assumed. Let V_t denote the maximum expected present value of utility over the remaining t periods. Using ρ_{jk}^{γ} to denote the transition from weather outcomes m to n, the individual will maximize

$$V_t(C_t,\ R_t) = \mathrm{Max}_{C_t, l_t, R_t, s_t}\ \{EU(C_t,\ R_t)\} + \beta \sum_{j=t}^{T} \emptyset_t\, U(\,C_{t+1},\ R_{t+1}) \qquad (5)$$

subject to (4). Given values for time and risk preferences, the problem can be solved numerically by backward recursion using dynamic programming (DP).

3.2 Estimating Costs and Benefits to the Farmer

The costs and benefits can be calculated via two approaches. In the first approach, the researcher can directly obtain the expected utility by evaluating the perceived costs and benefits associated with production with and without CIS under the different states i.The aggregate expected utility will be expressed as follows.

$$\sum_{K} EU\ (C_t,\ R_t)\ = \sum_{k}\sum_{i} U_t\big(C_t,\ R_t; \gamma_{jm} = 1\big) - \sum_{k}\sum_{i} U_t(C_t,\ R_t; \gamma_{jm} = 0) \qquad (6)$$

The outcomes included in the analysis are, for different states of nature (for instance good, moderate, and severe weather realizations):

- Agricultural yields and payoffs with and without CIS use, as captured through $Y(\cdot)$
- Inputs costs and other investments in agriculture to capture production costs, A_{ikt}
- Incomes from various non-farm activities, time allocated to farm and non-farm activities (l_{ikt} and L_{ikt}, respectively),

To determine alternative states of nature, it is useful to capture any shocks experienced and the average recovery time from shocks. Table 2 provides a framework of how the researcher will present the costs and benefits for the various CIS types and distribution by gender.

Table 2: Costs and Benefits of CIS

	Using CIS				No CIS	Difference
	Advisory services	**Participatory services**	**MWF**	**IK**		
Women						
Expected Outcomes (Y)						
Bad weather						
Moderate weather						
Good weather						
Men						
Expected Outcomes (Y)						
Bad weather						
Moderate weather						
Good weather						
Aggregate						
Expected Outcomes (Y)						
Bad weather						
Moderate weather						
Good weather						
Percentage difference in benefits accumulating to men as opposed to women						
Percentage difference in costs accumulating to men as opposed to women						

The second approach is the of use empirical simulations to find a new set of farm payoffs that will be realized if farmers used CIS in making production decisions.

4. Conclusion and Next Steps

The briefing note has provided a detailed framework of using an expected utility framework to evaluate the costs and benefits of providing CIS to farmers in SSA. Unlike the conventional methods of using the net present value (NPV) of future cash flows, our approach allows for the valuation of non-monetary outcomes such as improved consumption smoothing when exposed to climate shocks, changes in time use, and the intra-household distribution of the costs and benefits. The note also provides details on quantifying the variation of costs and benefits with different CIS packages.

Moving forward, we intend to expand the framework to accommodate the costs incurred by the CIS providers and allow for variation of the costs and benefits among different CIS distribution channels. The team will also develop the computer software and work with various country teams to collect data that will allow us to quantify the country-specific CIS costs and benefits. We welcome any feedback that can help us to refine the tool and tailor it to country-specific needs.

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Annex 1.

Evaluating the intrahousehold CIS costs and benefits will require both household- and individual-level data. The data will be collected from key male and female decision-makers within the households. The tool for the data collection is available ***here***. Below is a summary of the different data modules and how they will be used in the utility framework:

Module A. Household and individual demographic characteristics

This section will collect household and individual demographic data. This includes the gender of the household head, number of decision-makers, age, education, literacy levels and livelihood activities of the primary and secondary decision-makers, and household size. The data will be used in understanding the CIS adoption and differential impacts among men and women, and the intrahousehold distribution of the costs and benefits.

Module B: Perceptions about climate change, and CIS use

When farmers decide to adopt technology such as CIS, they not only consider the immediate expected benefits but the availability of benefits in multiple future periods. This section will ask questions about the farmers' perception towards climate change (based on ten years), CIS access, type of CIS accessed, channels of delivery, and use of existing CIS technologies in making agricultural production decisions. This data will be important in understanding who uses CIS, how the farmers' perception toward climate change influences CIS adoption decisions, the extent of use, and the climate conditions under which farmers are likely to use the technologies. In addition, the costs and benefits of CIS are expected to vary with the type of technology and the delivery channels used. This data is important to evaluate the cost-effectiveness of providing specific CIS packages to men and women and it will be useful in tailoring the packages to meet the gendered needs.

Module C: Yield Expectations

This section will collect data about agricultural production and productivity indicators for major crops that were cultivated in the last season. Crop yields will be defined as the output per unit of land (kg/ha). Information about the weather-induced variation in crop productivity will also be collected. This information will be matched with crop prices to estimate the agricultural payoffs under CIS and non-CIS production. To understand how the gendered distribution of farm profitability, the section will also collect data on income allocation decision making.

Module D: Time allocation in crop production

CIS will not only have direct impacts on-farm productivity and profitability, but some recommendations might have direct implications on labor allocation which might differently affect men and women. In this section, the researcher will ask questions about time allocation in the production of major crops identified in module C for both men and women decision-makers. The data will be used to evaluate whether CIS can contribute to individual empowerment via reduced workload and promoting individual work-life balance and will enter the expected utility model as leisure.

Module E: Other Sources of Income

Besides crop production, the researcher will need information on the incomes from and time allocation to other agricultural and non-agricultural incomes. Most households in SSA obtain their incomes from livestock production and allocating their labor in salaried or waged off-farm activities. This section will collect data about the expected annual incomes from livestock production and off-farm activities for both decision-makers under the three climate scenarios, and the average amount of time that men and women allocate to each activity. The data will be used in understanding the gender-based income uncertainty, the time burden associated with varying climate conditions, and the impact of CIS on individual and household income flows.

Module F: Expenditure on Agricultural Activities

In order to conduct a cost benefit analysis, it is important to understand the costs associated with each production regime. This section will collect information about the costs incurred by the farming household across different climate scenarios. This data will be collected from the primary respondent.

Module G: Risk and time preference

Risk and time preference are important factors in CIS adoption because the ability to adopt and use CIS recommendations can be influenced by what farmers perceive as risks as well as how they rank them and farmers discounting factor. The section borrows from the Global preference Survey approach (available here). In the intertemporal expected utility risk and time preference are important in determining the weights when summing over multiple state of nature where, more risk averse individuals will attach a higher weight to states of nature with lower consumption, and when summing over multiple years, where more impatient individuals will attach a lower weight to future years. The **risk preferences** will be elicited through a series of related quantitative questions consisting of a series of five binary choices. Choices will be given between a fixed lottery, in which the individual could win x or zero, and varying sure payments, y. Choice of the lottery results in an increase of the sure amount being offered in the next question, and vice versa, thereby zooming in around the individual's certainty equivalent. **Time preference** is derived from a quantitative survey measure consisting of a series of five interdependent hypothetical binary choices between immediate and delayed financial rewards. In each of the five questions, participants have to decide between receiving a payment today or larger payments in 12 months.

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