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**Guyana**

**Sustainable Agricultural Development Program**

**(GY-L1060)**

**Economic Analysis Annex**

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# Introduction

Agriculture is an important activity in Guyana where it serves as a basis for sustaining rural livelihoods and domestic food security, and is an important source of foreign exchange earnings. Agriculture is responsible for 18% of Gross Domestic Product (GDP) and 20% of overall employment, reaching up to 70% in rural areas (Government of Guyana, 2012). Agricultural land use is around 1.74 million hectares, however, only 200,000 ha of this area is considered to be used effectively with adequate drainage and irrigation; non-traditional crops occupy about 40,000 ha of this area. It is estimated that an additional 3.3 million hectares could be brought into productive use.

Guyana’s National Land Use Plan estimates that 68% of Guyana’s land surface has soils suitable for agriculture (Ministry of Agriculture, 2013). Traditional agricultural crops are sugarcane and rice while non-traditional crops which are increasing in importance are coconut, cassava, orchard species, vegetables, botanicals and herbals. Fisheries, livestock and small ruminants are also important. Agriculture is highly concentrated geographically, with the exception of cassava, on the narrow strip of coastal plains.

Non-traditional agriculture is similar in input use to subsistence farming in Guyana, and is small scale, uses low technology and is highly labor intensive (Government of Guyana, 2012). Agricultural productivity is generally low, even for Guyana’s most important export oriented crops, namely rice and sugar. Small farmers are responsible for the production of most of the fruits, vegetables and grains; yield of crops such as corn, beans and small scale rice production are 40% lower than that of its Caribbean neighbors and 60% lower compared with the rest of South America.

Guyana’s vision for agriculture by 2020 is to transform agriculture from a subsistence-based activity to a source of wealth generation and entrepreneurial innovation to produce food and non-food commodities to meet local and export demand (Ministry of Agriculture, 2013). Previous efforts have focused on the 5-C’s (citrus, cassava, coconut, cocoa and cattle) while more recently, efforts have been on the 4-Ps: pepper, plantain, pineapple and pumpkin. The Ministry of Agriculture’s (MoA) latest Agriculture Strategy (2013-2020) is pursuing an F-5 approach which emphasizes: food security; fiber and nutritious food; fuel production; fashion and health products, and; furniture and crafts.

To assist Guyana in achieving the goals set forth in its Agriculture Strategy, the Inter-American Development Bank is supporting the Government of Guyana with GY-L1060, the Guyana Sustainable Agricultural Development Program. The main objective of the US$15 million program is to increase the productivity of the agricultural sector while maintaining a sustainable and climate resilient use of natural resources. Impacts will be achieved through a combination of institutional strengthening, research, extension and support to farmers for technology adoption. It is expected that higher productivity will also reduce pressure on forests and fragile ecosystems, and at the same time, increase incomes for small and medium-sized farmers. Activities will be concentrated in Region 5, 9 and 10, where agricultural potential and availability of natural resources is greatest.

The Program is organized in three components:

***Component 1:*** Generating information for evidence-based policy making and natural resource management (US$4.170 M). This component will include the review and design of an appropriate Agricultural Information System (AIS), including the preparation and implementation of an Agricultural Census;; strengthening of the Monitoring and Evaluation capabilities of the MoA; identification of buffer zones for sensitive wetlands (with potential to designate a RAMSAR site) in Region 9; and identification of water catchment sites for improved natural resource management and climate change adaptation in Region 9.

***Component 2:*** Strengthening of the agricultural innovation and extension system (US$6.398 M). The program will finance the establishment of agriculture centers, to contribute to local and regional development, including technology transfer, demonstration and training. Two centers have been identified by the MoA: (i) Lethem/Manari (Region 9); and (ii) Ebini (Region 10). In both sites, the program will finance infrastructure (new infrastructure and upgrades to existing buildings), equipment and technical assistance. The infrastructure will be used for research, training and extension. Land is owned by the government and will be provided by the MoA. Research/demonstration programs, identified through a prioritization exercise, will be implemented in collaboration with national and international centers. These programs will identify specific beneficiary groups, technology packages and monitoring and evaluation mechanisms. Research activities will focus on reducing vulnerability to climate change through multiplication and conservation of genetic material, including drought resistant varieties and protection of traditional knowledge as local adaptation strategy.

***Component 3:*** Support for compliance with sanitary and phytosanitary standards (US$2.80 M). Access to markets and infrastructure will increase the value and sales volume of meat and other high value products. To this end, the program will finance: (i) the review and update of standards and codes related to products destined for export markets as well as local markets, both current and potential; (ii) the implementation of pilot facilities (infrastructure and equipment) for meat in regions 9 and 5 to evaluate the feasibility and unit costs of complying with standards; and (iii) training and technical assistance for the Guyana Livestock Development Association (GLDA) and other producer associations.

In addition to the three components, US$1.632 M is allocated to management, auditing, and monitoring and evaluation. Operations and maintenance costs of the facilities are considered in the cost benefit analysis presented herein and assume a 4% cost applied to the value of infrastructure upgraded or constructed for the period of analysis (2017 to 2040).

This Economic Analysis evaluates the economic viability of GY-L1060 and is organized as follows. The next section provides a brief overview of the beneficiary regions. Section II offers a review of the evidence on the economic impacts of agricultural research and extension. Section III presents the two-stage methodology to the assessment which consists of a break-even analysis and cost benefit analysis based on a survey-driven characterization of the current agricultural system 1 and hypotheses about a potential future system 2 state with Program interventions. Section IV provides an overview of the anticipated benefits of the Program and Section V reviews the costs. Section VI reviews the results of the two-staged analysis and offers a sensitivity analysis of the results. Section VII closes the report with key findings.

## An Overview of Beneficiary Regions

### Region 9.

Region 9, also known as the Rupununi, Upper Takutu-Upper Essequibo is Guyana’s largest region, occupying one quarter of the country’s terrestrial land mass. Region 9 has a population of over 24,000 divided into three Amerindian tribes, namely the Makushi, Wapishana and Wai which reside in 33 settlements. In general, over half of the families in the region engage in mixed farming as a principal livelihood activity with both subsistence and cash-based activities. Mixed farming includes cassava, peanut, banana, and other fruits and vegetables. Other economic activities include the harvest of non-timber forest products, wildlife and timber, and the production of crafts and mining.

There is potential for agricultural expansion in the region; a 1963/1964 soil survey undertaken by the Food and Agriculture Organization of the United Nations (FAO) on 18,965 m2 of the region classed 1% of the surveyed area as good to moderate agricultural land with another 49% classified as poor but with potential for fertilization and cultivation. Average rainfall varies considerably throughout the region, though the long-term annual average is about 1,500mm. The average monthly temperature is 31ºC. In terms of surface water, 30% of the rivers have consistent flow throughout the year, while many others flow seasonally with good potential for water capture for agricultural purposes. Groundwater data for the region is generally lacking. With regard to vegetation, half of the region is covered with lowland mixed forests scattered about the savannah, and mountainous mixed forests which occupy the hillier terrain (FAO, 2013).

Cassava is the main agricultural good produced, though it remains largely a subsistence crop and activity. Cassava production technology is rudimentary in all of its aspects with almost no inputs used for fertility or pest control. Total cassava production across Region 9’s sub-districts totals 2,036,628 kg over 182 hectares for a yield of around 11.2 tons per hectare[[1]](#footnote-1). Peanut is the region’s second crop and also has commercial importance. The potential impact of agricultural extension is demonstrated through the experience with peanuts in the region which was promoted by USAID through a six year Peanut Collaborative Research and Support Program from 2002 to 2007. The extension program emphasized improved productivity, storage and production systems. Various technologies were introduced including those related to pest management, crop nutrition, land preparation and mechanization. In the absence of formal statistics, it is estimated that the peanut program helped increase yields from 1.3 tons/ha to 3.1 tons/ha (Haire, 2007).

Rice production was introduced in the 2000’s with some pilot projects initiated. While initially introduced at a medium scale, farmers have since been encouraged to cultivate independently smaller plots. There are a number of challenges to be met if rice production is to continue and increase, including addressing availability of planting material and maintenance of equipment. Santa Fe Farms is the one large farm in the region, sized at 10,000 acres; it plants rice and raises large and small ruminants.

Vegetable cultivation is concentrated east of Lethem, though cultivation has fluctuated and perhaps declined since improvement of the Linden to Lethem road. Pumpkins, bananas, corn, blackeye pea, beans and peppers are cultivated. In terms of orchard species, cashew, mangos, avocados and citrus may be found in the region, though little effort has been made to establish organized orchards despite apparently good potential for production.

Livestock follows an extensive grazing system of rearing cattle. Pigs, poultry and small ruminants are generally fed crop residues. FAO (2013) classifies the livestock systems in the region as grazing, mixed farming and intensive. The extensive system has animals requiring up to 2 ha per animal unit and at least 5 years to reach a market mature weight of 350 kg. These extensive systems pose problems such as high mortality, poor gains and theft. Nonetheless, these systems are an important component of Amerindian livelihood strategies and there are a number of large operations in the region, despite declining numbers.

Cattle systems are low technology with little use of improved forage; productivity is consequently also low and certainly poor when compared with improved pasture systems in neighboring Roraima, Brazil. Live weight on Guyana’s side of the border is 400 kg at 5 years compared with 407 kg at 3 years. The stocking rate is 1 animal units per 25ha in Region 9 compared to 0.72 animal units per ha in Roraima (FAO, 2013). Beef production in the region is reported as 8,220 kg/month, though the actual figure could be higher due to animals slaughtered outside of proper facilities and therefore not recorded.

Small ruminants, primarily sheep, are second in importance to cattle in the region as an income activity, marketed largely to the coastal region. As with cattle livestock, these systems use low technology and inputs. A reported 400 kg of mutton is slaughtered per month along with 122 kg of goat. The savannah pig, once more popular, is in decline due to its destructive grazing habits and uncleanliness. Approximately 350 kg of pork is slaughtered per month. Creole fowl on the other hand is a critical source of eggs and meat in all of the villages of the region. Production could be scaled up if sources of feed could be enhanced (FAO, 2013).

### Region 10.

Region 10 is also known as the Upper Demerara-Upper Berbice; it has 17,040 km2 of territory and is situated south of the Coastal Plain which is between 150 to 250 km wide. Topography is relatively flat to undulating with hillier areas to the south and west. The region forms part of the Hilly Sand and Clay and Highland Forest zones of Guyana. Vegetation cover ranges from open savannah to a rather sparse scrub savannah with what appears to be typical forest subclimax vegetation. The soils are mostly coarse-textured, ranging from sands to sandy loams, and are characterized by low cation-exchange capacity, high percent aluminum saturation, low base saturation, and low available phosphorus and most of the other nutrients. They are low in organic matter and structurally highly unstable (Simpson, 2016).

The regional climate is a tropical humid lowland climate with a 19ºC minimum and 32ºC maximum temperature and annual precipitation around 2,250 mm with a marked rainy season from April to July and October to December. The Essequibo, Demerara and Berbice Rivers dominate surface water supply while groundwater resources are also known to be abundant in the north and east of the Region. The Dakoura Creek Watershed is particularly important as it replenishes Region 4’s freshwater supply as well as most of Guyana’s coastline (Ministry of Communities, 2016).

Region 10 has a population of 39,452 with 10 Amerindian settlements. Seventy percent of the population resides around the town of Linden where 29,232 people reside (Bureau of Statistics, 2016). Eighty-five percent of the food consumed in Region 10 is imported and there is no large scale agricultural production in the region with small scale cash crop farming concentrated on the Demerara River, around Linden, Moblissa and in the Intermediate Savannah. Low levels of agricultural productivity are reportedly due to lack of appropriate technologies and unclear land tenure.

Despite current low levels of production, the area has good potential for expansion given the abundance of land and the absence of flooding. The Intermediate Savannahs of Region 10 are recognized as the second major frontier for agricultural expansion in Guyana. The Savannah spans 292,038 hectares, 87,000 of which has brown sandy, well drained soils and known to be easily mechanized and responsive to fertilizer. Traditional crops in the area include black eye peas, cabbage, eggplant, hot peppers and bell peppers. Traditional fruit are pineapple, carambola, mango, orange, lime, grapefruit, guava, cherry, avocado, sapodilla and passion fruit. Nontraditional crops with strong potential are broccoli, cauliflower, sweet corn, cantaloupe, butternut squash, zucchini, iceberg lettuce, while other crops with potential are maize, peanut, soybean, cowpeas and pigeon peas (Ministry of Communities, 2016).

### Region 5.

Unfortunately, there is little published information available characterizing Region 5. What is documented is that Region 5, also called the Mahaica/Berbice, is responsible for almost 50% of national rice production, 30-35% of livestock and 10-15% of national sugar production (Ministry of Agriculture, 2013). The population of Region 5 is 49,723 (Bureau of Statistics, 2016).

# II. The Role of Research and Extension in Elevating Farmer Productivity; A Brief Review of the Literature

An early study by Birkhaeuser et al (1991) evaluated two studies on the effect of extension on knowledge diffusion, 8 studies on the impact resulting from adoption of improved technology, 15 farm level studies evaluating productivity impacts where extension was defined as a farm level variable, 9 studies used an exogenous extension variable, 10 productivity studies using aggregate output and extension variables, five studies analyzing the impact of extension on farmer profits. In summary, 36 of the 48 studies reviewed by the authors show a significant and positive extension impact, though there was some variability of the results in terms of some areas or crops of a particular study exhibiting a positive extension impact, while others within the same study did not, with little explanation of potential causes of this variability. This early study identified some methodological problems in the studies reviewed, including endogeneity in observed extension and farmer interaction, inter-farmer information flows and non-random placement of extension efforts. Birkhaeuser (1991) conclude that while there is a clear positive impact of extension, whether or not these activities are profitable remained at that time an open question due to a lack of research in this area. Those studies that did estimate returns to extension found generally high rates of return to the investment in both developed and developing countries (Birkhaeuser et al., 1991).

While agricultural research and extension may be shown to improve productivity, from a policy and investment perspective, it is critical to also consider costs and economic returns of interventions. Of the studies reviewed by Birkhaeuser et al (1991), eight of the studies undertook analysis of net returns to agricultural extension for 4 countries and one was a multi-country study. Another challenge to evaluating net returns to agricultural extension is that benefits and costs are distributed over time, where estimates of benefits usually occur at one point in time. Assumptions about how these benefits are distributed are therefore necessary. Of the studies evaluated, one study of extension impacts in the United States indicates returns of over 100%, though returns were differentiated by crop. The multi-country study in Latin America reported high returns (above 80%) to extension efforts in cereals and negative returns for staple crops. Analysis conducted in various localities in Eastern Brazil show rates of return ranging from 13% to over 500%, while other studies in India show returns that hover around 15%. Returns to cereals extension in Africa and Asia were 34% and over 80%, respectively and over 80% for both regions where staple crops are concerned (Birkhaeuser et al., 1991).

Romani (2003) evaluates the impact of agricultural extension on productivity using a panel sample for Cote d’Ivoire between 1997 and 2000, controlling for farmers’ unobservable characteristics with individual fixed effects. The author finds that extension services have generally been favorable for agricultural production, though the impact differed by crop. The impact of extension on production was found to be in the range of 30% improved yield, which Romani (2003) states is consistent with the literature on the short run impacts of extension on crop production.

The World Bank’s Independent Evaluation Group (2011) analyzed 86 impact evaluations conducted between 2000 and 2009, 17% of which were for Latin America and the Caribbean. The greatest proportion of these focused on land or extension interventions and to a lesser degree, market arrangements, irrigation, natural resources management, input technology and microfinance. The review found that 62%, 42%, 56% and 87% of interventions had a positive impact on yields, income, production and profit, respectively. In terms of the constraint addressed, it was found that 63% of the interventions that focused on output and post-production processes had a positive impact, 61% of those addressing access and quality of inputs and 61% addressing farmer knowledge had positive impacts, while 37% of the studies that addressed the quality of land and farm resources had a positive impact. The review concludes, however that the evidence on the impact of agricultural interventions is thin, while the diversity of approaches and indicators used poses a challenge for reaching strong conclusions. This heterogeneity of methods and indicators also inhibits the application of meta analytical techniques (Independent Evaluation Group, 2011).

An IDB (2010) Development Effectiveness Overview reviews the evidence on the effectiveness of interventions in the agricultural sector. In the area of export promotion, sanitary and phytosanitary measures have contributed positively in a number of cases reviewed including that of Peru’s National Agrarian Health Service (SENASA) by opening market access through compliance with international standards. In addition, interventions that involve establishing agro-processing facilities can be effective in creating market linkages between rural and urban areas. In some country contexts like that of Guyana, these facilities may not be established when left to the private sector. Where poverty reduction and rural development are keystone to agricultural interventions, investments in these settings may be considered a public good. There is, however, little empirical evidence on the impact of public investment in these facilities (Inter-American Development Bank., 2010).

Cavatassi et al (2012) evaluate the Plataformas program in Ecuador which aimed to reduce transaction costs for famers by providing support to meet the needs of high value markets and direct marketing. Training to farmers was provided through farmer field schools for enhanced productivity and integrated pest management. Results of the evaluation show that the program improved the welfare of farmers by increasing yields and gross margins. These benefits were achieved through larger harvests, a larger share of the harvest being sold, and higher sale prices on the order of 30% higher than pre-intervention. Although the improved production systems had costs associated with them, the increased income more than offset these additional expenditure (Cavatassi et al., 2011).

Owens et al (2003) assess the impact of farmer contact with extension services on farm productivity using a panel data of households in three areas of Zimbabwe, controlling for selection and placement bias. The authors find that controlling for innate productivity characteristics and farmer ability with fixed effects estimation, extension services, defined as up to two visits per year, raised crop production by 15%. The authors did detect, however, variability in estimations across years in their longitudinal sample (Owens et al., 2003)

A study by Salazar et al (2015) evaluated ex-post the impact of Bolivia’s CRIAR program (Program for Direct Support of Rural Agricultural Initiatives). CRIAR aimed to increase smallholder food security and income by promoting technological adoption by means of non-reimbursable vouchers that financed 90% of the cost of a technological package provided to farmers. To control for participant endogeneity, an instrumental variable approach was used. Results from the analysis show that the annual value of production per hectare was 92% higher compared to the control group. The value of farm output sold in markets was 360% higher, net annual agricultural household income was 36% higher, and per capita income was 19% higher. Overall, participation in CRIAR was found to increase the probability of household food security by 32% (Salazar et al., 2015).

The Dominican Republic’s Program for Technological Support in the Agricultural Sector (PATCA) provided support for agricultural extension services for growing crops, livestock breeding and milk production, as well as improved health and food safety, and assistance for institutional reforms. An impact evaluation of PATCA’s extension component using propensity score matching showed that productivity of rice producers and animal breeders was enhanced (Gonzalez et al., 2009).

Farmer field schools, originally introduced in East Asia in the 1980s have become an important approach to reaching farmers and promoting technological innovation. Results from impact evaluations of field schools have been mixed and generally complicated by inadequate control for differences between participants and non-participants. Gotland et al (2004) conduct an impact evaluation of potato farmers in Peru testing the impact on farmer knowledge through a test score compared with a comparison group identified through propensity score matching.

Gotland et al’s (2004) study showed that participating farmers demonstrated considerably more knowledge of the subject matter, integrated pest management, than did non-participants. Since the study was conducted while the farmer field school was in its first year of operation, it was not possible to ascertain impacts on yields. Nonetheless, by examining cross-sectional variation in the subsample of non-participating farmers, it was found that knowledge of integrated pest management was positively correlated with yields, with simulations showing that field schools had the potential to raise productivity by 32% (Godtland et al., 2004).

Praneetvatakul and Waibel (2006) develop a two and three stage difference in difference model to assess the economic and environmental impacts of farmer field schools on crop and pest management of rice farming in Thailand. Results showed that participants tended to retain their knowledge and continue to implement the integrated pest management strategies disseminated compared with non-participants who applied chemical pesticides with little knowledge on the adequate dosage. While the environmental benefits from integrated pest management were clear, direct economic impacts were difficult to measure due to small potential gains in yield and the small expenditure on pesticides as a share of total farm production costs (Praneetvatakul and Waibel, 2006).

Evenson (2001) reviews empirical studies that estimate the impacts of agricultural extension and applied research. The emphasis of the review is on farm-level, cross sectional studies and on aggregate farm production data for a region. In attempting to draw stylized facts from these studies, Evenson (2001) cautions that the impact evaluation literature should not be interpreted as a representative sample of research and extension programs due to selectivity bias where unsuccessful evaluations are less likely to be published, while successful programs are more likely to be evaluated. Nonetheless, the evidence is based on a large proportion of all agricultural research and extension programs, while the analysis of aggregate programs covers both successful and unsuccessful ones (Evenson, 2001).

Evenson (2001) draws some preliminary conclusions from the studies evaluated: studies that estimated internal rates of return above 40% were typically interventions in the area of prevention science, private sector research, and research on rice, fruits and vegetables. Interventions that were research oriented tended to generate higher internal rates of return when compared with extension activities. Commodity-specific research programs produced higher rates of return than aggregate research programs (Evenson, 2001).

In a comprehensive study by Alston et al (2000), the authors review 289 studies on returns to agricultural research and development; annual rates of return were on average 65%, with 80% for research, 80% for extension, and 47% for research and extension programs combined. Variation across studies was found to be attributable in large measure to assumptions about lag lengths and the nature of how research induces a shift in agricultural supply. The authors find that even after extracting outliers and those studies that did not include sufficient information on all explanatory variables, the range of rates of return was still large which rendered it challenging to explain differences in a systematic way.

Nonetheless, Alston et al (2000) report that a few stylized facts emerged, namely: (i) rates of return do not appear to be declining over time; (ii) higher rates of return are found in more developed countries; (iii) rates of return vary according to crop; (iv) lower rates of return are associated with those studies that involve both research and extension, and; (v) even lower rates of return are associated with studies that focus only on extension (Alston et al., 2000b, Alston et al., 2000a).

Pardey et al (2006) investigate the issue of attribution in agricultural research and development, examining how to attribute credit for increased yields using Brazil’s research expenditure on varietal improvements in rice, beans and soybeans between 1981 and 2003. In summary, the authors make explicit to which institutions they attribute the research undertaking and the benefits generated by the research. The authors also consider what would be reasonable assumptions about yield trajectories in the absence of the research. Beyond an estimate of the attribution of benefits to Brazil’s agricultural research institution, EMBRAPA, the authors demonstrate the importance of accounting for international and institutional spillovers in research, as well as transparency in the estimation of returns to research where explicit decisions are required and in some instances, there may be no empirical basis for a particular choice (Pardey et al., 2006).

## Approaches to Ex-ante Economic Evaluations

Ex-ante economic analysis of direct investment in agricultural research programs may be desirable, though time and resources during project preparation are a challenge that can impact the depth that such analysis may achieve. There is also little justification for conducting ex-ante economic impact analysis for those agricultural research and extension programs that focus solely on institutional development. While GY-L1060 has numerous investments targeting institutional development, a core goal is in developing research and extension to enhance farm productivity. As such, ex-ante economic analysis provides a structured approach to evaluating the investment decision and where data limitations are a serious constraint as in the case of Guyana, break-even analysis can help set realistic expectations. A few recommendations on the design of ex-ante economic analysis arise from an AKIS World Bank (2000) study:

First, agricultural research and development interventions should not be evaluated individually, but should consider all programs with similar goals, including those programs funded by others than the concerned institution. In the case of extension, it is possible to evaluate extension separately from research programs, particularly where technologies have been available for some time, though technology adoption has been low. Agricultural extension efforts may be evaluated through measures of cost effectiveness or unit cost for reaching a farmer or hectare affected. Break-even analysis is useful to show the minimum impact required to justify expenditure and may be used for extension activities, entire research programs or the specific investment of interest (World Bank, 2000).

During project preparation, it is recommended that the analysis focus on retrospective technology adoption and impact studies that demonstrate where the proposed technology has been successfully implemented elsewhere, and; case studies that are based on existing information and field oriented studies. The approach to the economic analysis should follow the logic of the economic surplus method which includes cost benefit analysis (Masters et al., 1996). Finally, while there is a tendency to simply use the analysis to justify an investment with a focus on one ‘answer’ (e.g. net present value), the economic analysis should develop a framework which can be used for testing assumptions, conducting scenario analysis and be used on an ongoing basis to evaluate investments, their costs and potential benefits subject to available information. It is both beneficial and recommended if this capacity is institutionalized within the relevant government ministries and not serve only as an external activity (World Bank, 2000).

In designing an ex-ante analysis, there are a number of issues to take into account in the study design, including: geographic and vertical spread of benefits; intervention impacts on product quality; challenges related to quantifying benefits of investments in institutional strengthening; research externalities; the range of research and interventions which can be difficult to quantify; time lags in perceived benefits and how to incorporate these in the absence of theory; uncertainty in the outcomes of research; difficulties in estimating costs of research and extension and allocating these to particular crops or systems; separating project and non-project benefits;

Specifically with regard to time lags, there are three lags that should be considered: a research time lag which is the time between research expenditure and the release of the technology; the adoption uptake phase, and; the depreciation phase which is the time it takes for the new research to be obsolete. Rules of thumb that have been used in various analyses are: a lag of 3 years for extension; 6 years for adaptive research; 15 for applied research, and; a 25 year lag for strategic research (World Bank, 2000).

The primary method used in ex-ante economic analysis is the economic surplus method, where adoption of a new technology reduces unit costs of production, shifting the supply curve to the right thereby increasing consumer and producer surplus. By considering the costs of the technology, net present value, internal rate of return, benefit-cost ratios and other indicators may be calculated. Where the analyst is not necessarily concerned with the distribution of benefits between consumers and producers, cost benefit analysis can generate reasonable estimates of economic benefits. In this case, it is assumed that demand is infinitely elastic and supply is inelastic or vice versa. To compare and rank various research programs, an efficiency index may be estimated which is a function of the adoption rate, the cost of the project, the price of the commodity, and the quantity of production affected by the project (World Bank, 2000, Winters et al., 2010).

In the case where benefits are not easily measured in monetary terms, cost-effectiveness analysis presents an alternative where benefits are measured in nonmonetary terms such as the number of farmers trained, compared to the cost of farmer training. This approach is used to compare different approaches to obtaining an output at the lowest cost. The result is the cost effectiveness ratio which is the ratio of cost per unit of benefit. Where the intervention acts in several areas such as improved information, farmer education and technology development, a weighted cost-effectiveness analysis may be undertaken. Finally, where the benefits of the investment are unknown or there is little basis for their estimation, a break-even analysis may be undertaken where the minimum benefit required for the investment to be viable at a particular discount rate and distribution of benefits and costs is estimated (World Bank, 2000).

Sensitivity analysis is important across approaches where the variables most important to an intervention’s economic feasibility are identified and their influence estimated. The switching value approach may be used to estimate the value at which an intervention’s NPV becomes zero, and is specified in terms of percentage change in the value of the variable for which the intervention NPV is equal to zero. The switching value of variables is presented in order of declining sensitivity. Where variables vary together, the sensitivity of NPV to changes in combinations of those joint variables is estimated (World Bank, 2000).

# III. Methodology

## Overview

The ex-ante economic evaluation of GY-L1060 was undertaken in two stages[[2]](#footnote-2). In the first stage, a break-even analysis was conducted in an optimization and cost benefit analytical framework to estimate the minimum level of economic benefit per adopting farming household required for the net present value (NPV) of the Program to be equal to zero. A 12% discount rate was used and the period of analysis was 2017 to 2040. Costs follow directly from the Project Management Report and include: Program costs estimated in the design stage, and; operations and maintenance costs of the agricultural research centers, extension activities, the meat processing facilities, and the opportunity costs of farmers’ time spent participating in agricultural extension and training programs. Key assumptions in the analysis are: the technological adoption ceiling which is the proportion of farmers that will eventually adopt the technologies, assumed to be 20% of the 5,000 targeted farmers, and; the adoption path which is assumed to follow a logistical functional form.

The second stage of the analysis used the farming household survey undertaken in July of 2016 (discussed further below) to characterize the current agricultural system across Regions. The current agricultural system will be referred to throughout as system 1. System 2 is the agricultural system the Program aims to achieve. Key variables to characterize the systems include: farm size, crop/livestock yield, crop/livestock prices and variable/fixed farming costs. To characterize system 2, Guyana’s national average yields achieved for the chosen crops and livestock were used. The opportunity cost of farmers’ participation in training as well as the costs associated with shifting to system 2 were considered in the analysis. This data was used to estimate economic benefits which were then used in a similar cost benefit analytical framework as in the break-even analysis. Three scenarios were evaluated: an average scenario, an optimistic scenario and a pessimistic scenario, each describing assumptions about system 2 percentage of national average yields achieved. Assumptions driving the results are a function of the characterization of system 2 in terms of crop/livestock yields and areas, the adoption ceiling and the rate of adoption.

## Break-even Analysis

The approach to the break-even analysis involves the development of a spreadsheet model in MS Excel and an optimization routine built into the spreadsheet with the MS Excel add-on ‘solver’. The model is used to vary the value of the ‘benefit’ parameter such that the NPV of this parameter multiplied by the number of adopters in each year, net the Program investment, operations and maintenance costs and opportunity cost of farmer time, is equal to zero. NPV is calculated over the period of 2017 to 2040 using a discount rate of 12%. The number of adopters each year is approximated by the logistical functional form depicted in figure 1. The modeler has the ability to modify the form of the function, the adoption ceiling, as well as stratify beneficiaries according to predetermined criteria, by region, for example.



Figure 1. Assumed adoption curve with 20% maximum rate of adoption; Source: authors’ own elaboration.

## Current and Potential System States

System 1, the current agricultural system is characterized based on data extracted from the farming household survey. The composition of system 2 was designed based on key survey findings, government priorities and preliminary analysis by Simpson (2016) on potential lines of research for the agricultural research centers. As such, two crops were targeted for research and extension, as well as cattle. The maximum potential yields used in the analysis for the two crops, bora bean and cassava, are the current national average yields being actually achieved in Guyana, as reported by NAREI and the Ministry of Agriculture. In the case of cattle, yields reported in FAO (2013) from the neighboring state of Roraima, Brazil were used to set the production frontier for potential meat production.

Together, these potential yields were used to characterize system 2, a snapshot of the system which the Program aims to achieve. Based on this data and assumptions concerning adoption ceiling and path, yields achieved, the costs involved in moving from system 1 to system 2, Program costs, and the opportunity cost of farmers’ time for participating in agricultural training and extension activities, the net marginal economic return to system 2 was calculated in a cost benefit framework. The NPV and IRR of the Program for each of the three scenarios were also calculated.

### Farming Household Survey

To inform Program design, the expost economic impact evaluation strategy, and the ex-ante economic analysis, a famer household survey was designed and implemented during the month of July 2016. The survey sample was stratified by Region, namely, Regions 5, 9 and 10 (figure 2 depicts Guyana’s Regions). The 2002 Population and Housing Census was used to establish the number of farming households by Region, which was 4,615 households for Region 5; 3,769 households in Region 9, and; 1,928 households for Region 10 (Bureau of Statistics, 2007). Thus, the total number of potential beneficiaries of GY-L1060 is 10,312 farming households.

Accurate information on the location of farming households was not available prior to the survey undertaking. Due to the absence of this data, the tight timeline for survey design and implementation, and logistical challenges, the survey sample was undertaken based on a random selection of villages with the number of households to be sampled within each village defined a priori. Stratification within Region 10 was undertaken according to Amerindian Communities and Non-Amerindian Communities. Regions 9 and 5 were not stratified since Region 9 is largely Amerindian and Region 5 does not have a consolidated Amerindian Community (Bureau of Statistics, 2007, Regional Democratic Council, 2016). In Region 5, 330 households were sampled; in Region 9, 350 households were sampled, and; in Region 10, 219 households were sampled.



Figure 2. Guyana’s Regions. Source: Bureau of Statistics (2007).

Household identification took place in the field following a non-probabilistic ‘snowball’ approach where enumerators interviewed a household identified by the survey supervisor, based on the supervisor’s local knowledge. The household was requested to provide identification information for other farming households in the village and in the process, an initial list of farming households was developed. Households to be surveyed were randomly selected and assigned from this list, and at each subsequent household interviewed, the list was expanded upon. This process was carried out until the household survey quota for the village was met (Schling, 2016).

A number of precautionary measures were taken to avoid bias in this non-probabilistic sampling method: (i) more than one interviewer was assigned to each village at the same time and at different points in the village to avoid the sample being biased toward a subsample of only those farmers within a village that knew or knew of each other; (ii) supervisors possessed local knowledge which facilitates the identification of a first candidate farming household, as well as knowledge of the layout of the village which enabled them to distribute enumerators throughout the village to ensure thorough coverage; (iii) the number of enumerators assigned to a given village was proportional to the population of that village; (iii) the interviewing of neighbors or famers involved in joint farming was emphatically discouraged in order to generate a sample that was representative of the entire village rather than pockets of farmers who know or know of each other, and; (iv) The distance between households did not in any way influence the households selected for surveying (Schling, 2016).

### Lines of Research for Field Stations

A strong national agricultural research system, investment and human capacity are necessary conditions to improve agricultural productivity and reduce poverty (Stads et al., 2016). Guyana is no exception to this reality, although it may benefit from significant technological spill-ins from its neighboring countries, primarily Brazil which is a regional leader in agricultural research and development.

To build on Guyana’s agricultural research system and enhance capacity, component two of GY-L1060 aims to design and implement research programs for the agricultural centers in Ebini and Lethem/Manari. Agricultural research and development programs will be identified through a prioritization exercise and implemented in collaboration with national and international centers. These programs will identify specific beneficiary groups, technology packages and monitoring and evaluation mechanisms. Research activities will focus on reducing vulnerability to climate change through multiplication and conservation of genetic material, including drought resistant varieties and protection of traditional knowledge as a local adaptation strategy.

To inform investment in the agricultural research system, a diagnostic is underway to: (i) analyze agriculture and livestock production systems, current research and extension activities, and the biophysical and socioeconomic factors influencing productivity; and (ii) develop a proposal for a research program to experiment with innovative integrated land management approaches for crop and livestock production (Simpson, 2016). To this end, field reconnaissance and analysis was conducted in June/July of 2016 to generate information on stakeholder needs and the vision for agricultural development in Regions 9 and 10 primarily. This analysis revealed that the vision is one of a Hub and Spoke farm systems model which integrates both large commercial farms and small farmers in a symbiotic relationship. The priority activities for Region 10 were identified as the orchard crops of avocado, citrus, guava and soursop; annuals such as cassava, corn, cowpeas and soybean row crops, and; livestock rearing focusing on cattle and sheep. For Region 9, priorities were the orchard crops of citrus, guava, mango and passion fruit; annuals including cassava, corn, rice and soybean row crops, and; in terms of livestock, cattle, sheep and goats (Simpson, 2016).

In light of the designation of these priority activities, the research programs designed for the agricultural centers should be aligned with these productive activities. As such, for Region 10, the following research challenges were identified: (i) water management to respond to soil characteristics and drought; low soil fertility; pasture management for low quality forage, and; improved varieties and breeds. In Region 9, the challenges were similar though water issues are largely related to the relative abundance and then absence of water arising from the flood and drought season.

Agricultural research and extension outputs for Regions 9 and 10 were determined through stakeholder engagement and review of institutional strategies. For Region 10, the orchard sub-program will: identify key species; produce seed and seedlings, and; develop and disseminate information products. Annual crop research will focus on identifying target crop cultivars; produce seeds and seedlings; develop and disseminate information products. Outputs related to livestock were the following: identify breeds and develop facility to breed beef cattle, sheep and goats; develop and disseminate information products; establish market mechanism for genetic resources; identification of quality grass and legume forage; generate plant material of selected grass and legume species; develop and disseminate technological packages; identify quality byproduct feeding material from crop program; establish facility for production of byproduct feed; establish facility for feeding trials.

Improved soil management is relevant across agricultural systems; research in this area will focus on: developing soil management practices; develop and disseminate information products, and; generating estimates of soil carbon sequestration for potential carbon market engagement. Also relevant across research activities are the extension and dissemination approaches which will include: on-farm trials and demonstration plots; field days and workshops; factsheets, newsletters and other; early warning weather bulletins, and; other information and communications technology (Simpson, 2016).

In Region 9, cattle ranching is the main activity with a total live headcount of 13,000, which is considerably lower than the historic high of 65,000. In terms of livestock and related research, the research program will focus on identifying breeds; establish facility for breeding as well as for collection and storage of semen; develop and disseminate information products; generate market mechanism for animal genetic resources; identify quality grass and legume forage species; produce grass and legume material for planting; develop and disseminate technological packages.

With regard to orchard species, proposed outputs emphasize identifying target species; produce seeds and seedlings for select species; develop and disseminate information products. Annual crop research will focus on identifying target crop cultivars; produce seeds and seedlings; develop and disseminate information products. Finally, across activities, soil management research will hinge on developing soil management practices for the region; developing and disseminating information products, and; estimation of soil carbon sequestration for potential engagement with carbon markets. The approach to dissemination and farmer outreach is similar to that of Region 10 (Simpson, 2016).

One advantage of Region 9 is its proximity and similarity to Roraima State in Brazil which has a strong and long-standing agricultural research and development program led by the national agency EMBRAPA. In this case, there is good potential for technological spill-overs and benefiting from the over 20 years of EMBRAPA’s agricultural research in the region. The research program at Lethem will aim to establish strong research collaboration with EMBRAPA.

# IV. Economic Benefits

The break-even analysis estimates the level of benefits required for the Program to be economically viable given assumptions on the adoption ceiling, adoption path, time horizon, discount rate, and Program costs. This minimum level of benefits is estimated in section VI, results.

In the second stage of the analysis, systems 1 and system 2 states were characterized. The system 2 state represents the potential benefits the Program aims to achieve. Bora beans, cassava and livestock were selected as the first system elements for productivity enhancements. Production, area, yield, price and cost data were extracted from the farming household database for bora bean, cassava and livestock. The extracted database was analyzed for anomalies (e.g. production of a crop but no area planted and vice versa; costs greatly exceeding returns, etc.) and cleaned.

For characterizing system 2 and potential benefits, crop yields were drawn from the current national averages being achieved in Guyana as reported by the Ministry of Agriculture and NAREI in their 2014 Annual Statistical Bulletin (Ministry of Agriculture., 2014). The current national average yield for bora bean was reported as: 11,836 kg/ha with a retail sale price of US$3.30/kg in 2014[[3]](#footnote-3). The current national average for cassava yields is reported as 11,096 kg/ha with a retail sale price of US$0.76/kg in 2014[[4]](#footnote-4). With regard to cattle, FAO (2013) reports that live cattle weight in Guyana is 400 kg/head at 5 years compared with 407 kg at 3 years in neighboring Brazil. Stocking rates also differ greatly with 1 animal units per 25 ha in Region 9 compared with 0.72 animal units in Brazil’s state of Roraima. These crop and livestock yields were used to characterize the potential economic benefits of adopting system 2.

To characterize system 1 and the benefits of system 2 adoption, a subset of the main household farmer survey was taken for each of the two crops of interest and livestock. The approach was as follows. For bora bean, from the sample of 917 households, 126 observations were eliminated due to anomalies in the data (area planted, but no production and vice versa, for example). Of the remaining 791 observations, there were 24 bean farmers planting on average 0.686 hectares for a total of 16 hectares across regions. The mean total harvest was 148 kg/farm, mean price USD$1.21/kg, and was yield 215 kg/ha. Expanding to the level of population, there are 313 bean farmers, planting in total 215 hectares of bora bean and harvesting 46,165 kg of bean.

Cost data was very sparse, with only 5 farmers reporting any costs associated with production. While actual costs may be quite low, this result seemed unreasonable, therefore, the average cost/ha incurred by the 5 farmers was applied to all bean farmers (US$302.34/ha). Given the level of production and this production cost, the mean net return per hectare was negative USD$0.87/ha.

In characterizing system 2 for bean production, the average national achieved yields for bora bean reported by NAREI are used which is equal to 11,836 kg/ha. This is considerably greater than the 215 kg/ha estimated from the survey. Three scenarios are undertaken representing an optimistic, average and pessimistic scenario. Specifically, the optimistic scenario assumes that 50% of the national average yield of 11,836 kg/ha is achieved while the average scenario assumes 35% of the national average is achieved. The pessimistic scenario assumes 25% of the national average yield is achieved.

The mean bora bean price of USD$1.21/kg is used which is also considerably lower than the USD$3.30/kg Georgetown retail price reported by NAREI, in 2014 (Ministry of Agriculture., 2014). Absent information on the costs of achieving the nationally reported average yields and the sparse information on costs extracted from the survey, it is simply assumed that costs per hectare are ten times higher in system 2 compared with system 1. Finally, the opportunity cost of farmers’ time spent participating in the agricultural extension and training programs is considered. It is estimated that adopting farmers spend 40 days over the course of 2 years participating in extension and training programs; the daily wage rate used is the minimum public sector wage rate of US$13.27/day.

In calculating benefits, what is of concern is the marginal change in net returns from system 2 adoption. As such, the adoption ceiling (as well as adoption path which is assumed to follow a logistical function) is a critical parameter. There are 10,312 potential beneficiary farming households across the three regions. The Program aims to target 5,000 of the potential beneficiary farming households. A conservative approach is taken across scenarios. Out of the 5,000 targeted households, the number of new beneficiaries is equal to 5,000 households less the number of current bean farmers, multiplied by the adoption ceiling which is set at 20% across scenarios. Therefore, there are 937 new bean farmer adopters (eqn. 4.1). In addition, 20% of current bean farmers are assumed to adopt, which represents an additional 63 adopters. Overall, 1,000 farmers, new and current, will adopt the new bean production technology (eqn. 4.2). Table 1 provides an overview of the key characteristics of systems 1 and 2.

eqn’ 4.1.

eqn’ 4.2.

Where:

* NA are new adopters, subscript *b* is bean, subscript *c* is cassava;
* CF are current farmers, and;
* TA is the total number of adopters.

Next, subject to the percentage of yield achieved in each of the three scenarios, and the adoption path, the net value of bean production for new adopters is calculated on an annual basis as in equation 4.3.

eqn’ 4.3.

Where:

* NV is net value of production for the crop in USD for subscript *na* for new adopters and subscript *ca* for current subscript crop *b* farmers that adopt the technology;
* PA is percent of targeted farmers adopting in year subscript *t*;
* A is the number of hectares of crop subscript *b* planted;
* NY is system 2 subscript crop *b* yield in kilogram per hectare for the crop, by scenario subscript *n* which corresponds to one of the 3 scenarios: a pessimistic scenario where 25% of the national average yield achieved; an average scenario where 35% of the national average yield is achieved, and; an optimistic scenario where 50% of the national average yield is achieved;
* P is the price of the subscript *b* crop in USD per kilogram;
* NC is the system 2 production cost of subscript *b* crop in USD per hectare, and;
* OC is the opportunity cost of farmer time for participating in training and extension.

In the case of current farmers, the net increase in value from bean production is calculated as the difference between the net value of bean production achieved under system 1, and that achieved under system 2 as in equation 4.4.

eqn’ 4.4

Where:

* OY is system 1 yield of crop subscript *b* in kilogram per hectare, and;
* CO is system 1 production cost of subscript *b* crop in USD per hectare.

eqn’ 4.5

Where:

* TV is total net value of subscript *b* crop.

The total value of bean production is the sum of the net value of production of new adopters and the increase in net value for bean production perceived by current bean farmers that adopt system 2 (eqn’ 4.5).

The approach to estimating benefits for cassava is the same as for bora bean, though the parameter values are different. Out of 917 observations, 135 were eliminated leaving 782 observations. Two hundred twenty-four of these farming households planted cassava with each household planting 0.779 hectares on average for a total of 174 hectares across regions. The mean total harvest was 1,729 kg/farm, mean price of USD$0.79/kg, and yield of 2,220 kg/ha. Expanding to the level of population there are 2,954 cassava farmers across regions, planting 2,300 hectares in total.

As in the case with bora bean, cost data was sparse, with only 35 farmers reporting any costs associated with production. Again, while it is expected that real production costs may be low, it seems probable that farmers are under reporting costs associated with production. As such, the average production cost per hectare of the 35 farmers was applied to all cassava farmers (US$138.76/ha). Given the level of production and this production cost, the mean net return is USD$1,619/ha.

In characterizing system 2 for cassava production, the national average achieved yields for cassava reported by NAREI are used which is equal to 11,096 kg/ha. This is considerably greater than the 2,220 kg/ha estimated from the survey. As with bora bean, three scenarios, the optimistic, average and pessimistic scenarios, take just a percentage of this potential yield; specifically, 50% of 11,096 kg/ha, 35% and 25%, respectively. The mean price of USD$0.79/kg is close to the Georgetown retail price of $0.79 reported by NAREI in 2014 (Ministry of Agriculture., 2014). Absent information on the costs of achieving the NAREI potential yields and the sparse information on costs extracted from the survey, it is simply assumed that production costs per hectare in system 2 are ten times those observed in system 1 (USD$138.76). As with bora bean, farmer opportunity costs for participating in extension and training activities are considered.

Out of the 5,000 targeted households, the number of new beneficiaries is equal to 5,000 households less the number of current bean farmers, multiplied by the adoption ceiling which is set at 20% across scenarios. Therefore, there are 409 new adopters (eqn. 4.1). In addition, 20% of current cassava farmers are assumed to adopt, which represents an additional 591 adopters. Overall, 1,000 farmers will adopt the new cassava production technology (eqn. 4.2). Table 1 provides an overview of the key characteristics of systems 1 and 2. The total net value of adoption is calculated as shown in equations 4.3 to 4.5.

Table 1. Key characteristics of systems 1 and 2 for bora bean and cassava. Source: Author’s own elaboration.



Finally, the approach to estimating benefits for cattle production is as follows. Of the 917 observations, 8 were eliminated leaving 909 observations. One hundred and thirty-four of those observations are cattle farmers with an average of 15 head of cattle per household and a total across regions of 1,967 head of cattle. On average, households sell 1.24 head per year at a mean price of USD$309.08/head; 166 head of cattle were sold in the previous year. Expanding to the level of population there are 1,520 cattle farmers, 22,314 head of cattle, and 1,883 head sold in the previous year.

Of the 134 households with cattle, only 51 reported any production costs. Similar to the approach with crops, extracting only those households that reported costs of production, the average cost/head was estimated and applied across all livestock farming households (USD$18.55/head). Given this level of sales and production costs, the total net return from cattle is USD$168,049.39.

In characterizing system 2 for cattle production, the estimations made here are based on FAO (2013). FAO (2013) reports that live cattle weight in Guyana is 400 kg/head at 5 years compared with 407 kg at 3 years in neighboring Brazil. Stocking rates also differ greatly with 1 animal unit per 25 hectares in Region 9 compared with 0.72 animal units per hectare in Brazil’s state of Roraima. The more rapid increment in live weight achieved in Brazil is used as the benchmark for the estimation of yield rather than the stocking rate. That live weight in Brazil is 407 kg in 3 years compared with 400 kg in 5 years in Guyana indicates that Brazilian yield per year is 70% higher than yields achieved in Guyana.

Again, three scenarios are undertaken, an optimistic scenario where 50% of the potential yields are achieved, an average scenario where 35% of yields are achieved and a pessimistic scenario where 25% yields are achieved. Table 2 provides an overview of the key characteristics of systems 1 and 2.

Table 2. Key characteristics of systems 1 and 2 for cattle. Source: Author’s own elaboration.



It is assumed that the survey reported number of heads of cattle sold in the previous year represents the sustainable level of production for system 1. It is then assumed that the increased production achieved in system 2 is sold which translates in to an additional 0.86 head/household sold per year if 100% of the yield increase were achieved. The costs of implementing system 2 are assumed to be 50% higher than those of system 1. As with bora bean and cassava, farmer opportunity costs for participating in extension and training activities are considered.

# V. Economic Costs

The total cost of implementing GY-L1060 is US$15M, which will be disbursed over a 6 year period. Disaggregating by program components, the breakdown is as follows:

* Component 1: Generating information for evidence-based policy making and natural resources management: US$4.170 M.
* Component 2: Strengthening the agricultural innovation and extension system: US$6.398 M.
* Component 3. Support for sanitary and phytosanitary measures: US$2.80 M.

In addition to the three components, US$1.632 M is allocated to management, auditing, monitoring and evaluation of GY-L1060. Operations and maintenance costs of the facilities are considered in the cost benefit analysis and assume a 4% cost applied to the value of infrastructure upgraded or constructed for the period of analysis (2017 to 2040). The cost of operations and maintenance in the CBA increases as new infrastructure is installed and existing infrastructure is upgraded. Once all infrastructure has been installed, operations and maintenance costs are equal to US$276,800 incurred annually beginning 2022.

Finally, the opportunity cost of farmers’ time spent participating in extension and training activities is considered a cost in the analysis. It is estimated that adopting farmers spend 40 days over the course of 2 years in participating in extension programs; the daily wage rate used is the minimum public sector wage rate of US$13.27/day. Figure 3 depicts the distribution of costs over the 6 year implementation period.

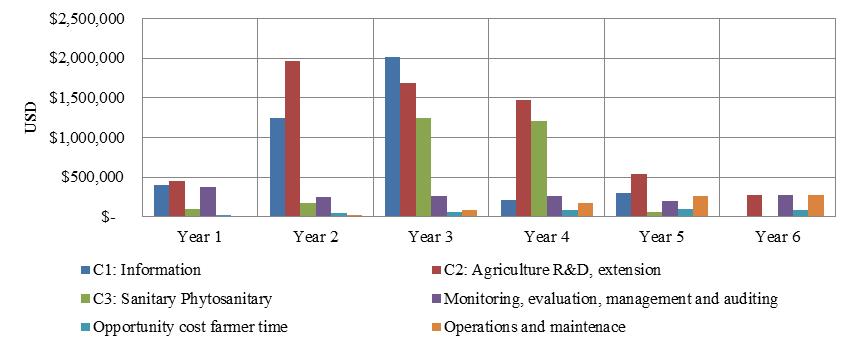


Figure 3. Distribution of Program costs by component. Source: Author’s own elaboration.

# VI. Results

## Break-even Analysis

Table 3 shows an extract (6 year Program execution period + 1 year) of the break-even analysis assuming a 20% adoption ceiling for the 5,000 targeted farming households. This adoption ceiling is reached in year 2028. The full period of analysis is 2040 and the discount rate is 12%. Twenty percent of the targeted beneficiaries is equal to 1,000 adopters. Given these assumptions, the Program breaks even with a minimum annual household benefit of US$2,196.

Table 3. Break-even analysis, 20% adoption ceiling. Source: author’s own elaboration.



## Cost Benefit Analysis: System 2

A cost benefit analysis of adoption system 2 was undertaken. A number of driving assumptions are noted: the assumed adoption ceiling is 20% in all simulations and the number of target beneficiaries is 5,000. The adoption pathway follows the logistical functional form in figure 1. Three scenarios are undertaken. The first optimistic scenario assumes that 50% of national average yields discussed in section IV are achieved. The average scenario assumes that 35% of national average yields are achieved, and the pessimistic scenario assumes only 25% of national average yields are achieved.

Table 4. System 2 cost benefit analysis, 50% of yields achieved, 20% adoption ceiling. Source: Author’s own elaboration.



Table 4 provides an excerpt of the optimistic scenario where 50% of yields are realized. This scenario generates an NPV of $ $16,194,346 and IRR of 31%.

Table 5. System 2 cost benefit analysis, 35% of yields achieved, 20% adoption ceiling. Source: Author’s own elaboration. 

Table 5 provides an excerpt of the average scenario where 35% of yields are realized. This scenario generates an NPV of $1,531,706 and IRR of 14%.

Finally, Table 6 provides an excerpt of the pessimistic scenario where 25% of yields are realized. In this scenario, the NPV is negative $8,243,387 and a negative IRR of 1%. Given the conservative assumptions made throughout, this is an unlikely scenario.

Table 6. System 2 cost benefit analysis, 25% of yields achieved, 20% adoption ceiling. Source: Author’s own elaboration.



## Sensitivity Analysis Summary

In the breakeven analysis, with an adoption ceiling of 20% of 5,000 targeted beneficiaries, a minimum household benefit of US$2,196 is required for the Program to break-even.

Assessing the sensitivity of results to assumptions about the percentage of potential yields achieved, in the optimistic scenario where 50% of yields are achieved the NPV is US$16,194,346 and the IRR 31%; where 35% of yields are realized, NPV is US$1,531,706 and IRR 14%. Finally, in the pessimistic scenario where 25% of yields are realized, NPV is negative US$8,243,387 and the IRR is negative 1%.

Sensitivity around the adoption ceiling is also tested, varying the adoption ceiling from 2% to 50% of potential beneficiaries. Figure 4 provides the results of this analysis.

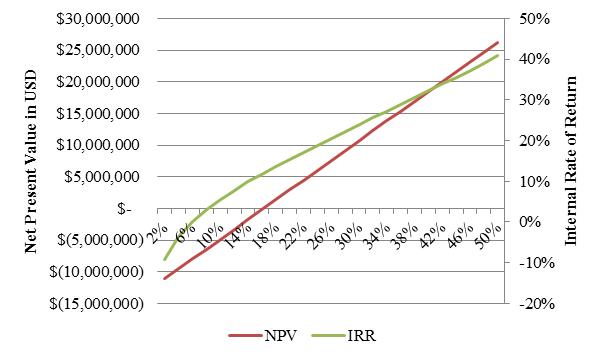


Figure 4. Sensitivity of NPV and IRR to adoption ceiling with 5,000 targeted beneficiaries, 35% of national yields achieved, and a 12% discount rate. Source: Author’s own elaboration.

These results indicate that the Program begins to break even when the adoption ceiling is 18.03% or greater, assuming 35% of national yields are achieved.

# VII. Conclusions

The analysis conducted here has shown that average expectations would have the Program generating an NPV of US$1,531,706 and IRR 14% if 35% of national average yields are realized, subject to an adoption ceiling of 20% and 5,000 targeted farming household beneficiaries. The sensitivity analysis confirms the robustness of these results with a minimum adoption ceiling of 18% required for the Program to break even given 35% of potential yields are achieved and other conservative assumptions made throughout.

# Appendix A. Multi-Dimensional Trade-Off Analysis model (TOA-MD)

The third stage of the analysis, which is currently underway, is the calibration and application of the Multi-Dimensional Trade-Off Analysis model (TOA-MD) to estimate possible levels of technological adoption and economic returns (Antle, 2011). Estimations are subject to individual farm opportunity costs of switching between the current crop-livestock system, system 1 and; the with Program crop-livestock system, system 2. Key variables for model calibration include: farm size, crop/livestock yield, crop/livestock prices, variable/fixed farming costs, non-farm income, and costs of transitioning from system 1 to system 2. Estimated with Program returns are estimated with TOA-MD and then evaluated alongside Program costs in a cost benefit analysis. Assumptions driving model results are a function of the characterization of system 2 in terms of crop/livestock yields and areas which are extrapolated from the literature and the subject of sensitivity analysis. Three scenarios are evaluated: an average scenario, an optimistic scenario and a pessimistic scenario, each describing assumptions about system 2.

The TOA-MD Model is a statistical model developed for multidimensional impact assessment to simulate impacts and adoption rates of new farm technologies in a heterogeneous farm population. The model simulates what would be observed if it were possible to undertake a controlled experiment to provide a best approximation of the impacts of implementing new farm-scale technologies. Estimated impacts are reported in terms of population means or proportions of the population above a reference level such as a poverty line. Sensitivity analysis is a key feature of the framework which enables the user to assess model robustness to critical parameters.

In terms of the types of agricultural technology adoption packages the framework is suited to assessing, these include the introduction of new crop varieties, improved crop and livestock management strategies, the implementation of soil conservation and agroforestry measures, and integrated agriculture-aquaculture systems among others. Importantly, the model does not solve for market equilibrium (Valdivia and Antle, 2012). TOA-MD coupled with a computable general equilibrium model on the other hand could be used to estimate farm level impacts of improved technology and how changes in production affect interactions with other sectors, factor demand, employment, income, prices and other variables of interest.

The TOA-MD framework can be used for two types of ex-ante economic analysis. The first is exploratory analysis to understand how a change in technology would affect a particular outcome subject to reasonable assumptions about farm characteristics, prices, and agent behaviors such as farmer attitudes toward risk. The second type of analysis is predictive involving analysis of technology adoption and impacts on a population with predicted farm characteristics and prices, and assumptions on agent behavior. The use of TOA-MD as a predictive tool is more demanding; it requires a valid model and sound knowledge of farm characteristics, prices and agent behavior (Antle et al., 2015).

This study applies TOA-MD in the second type of ex-ante economic analysis to estimate the potential economic returns to farmers from GY-L1060 subject to farm and market parameter estimates and behavioral assumptions. TOA-MD takes a population-based approach to analysis of agricultural systems which is a departure from representative farm models that use average or aggregate data (Antle et al., 2014). The TOA-MD approach takes into account the heterogeneity of farming systems and self-selection behavior, which as mentioned earlier, is a challenge where ex-post economic impact evaluations are concerned. The model is designed to be parsimonious; this is important when the model is used to generate estimates that are out of sample or unobservable. Model calibration is based on observation, as well as experimental, modelled and expert data, depending on data availability (Antle et al., 2014).

A first step in designing in impact assessment with TOA-MD is to stratify the population into similar subpopulations; stratification is necessary to improve the normal statistical approximation used in the model. Farm size or farm-level returns often provide a reasonable starting point for this stratification. In the present analysis, the population of farms is stratified by region. Expected returns for farms of each system are assumed to be normally distributed, thus implying that opportunity costs are also distributed normally. Further stratification can increase the accuracy of this assumption. Although opportunity costs and expected returns are assumed normally distributed at the strata level, on the aggregate population level, the distribution is often non-normal as it represents the aggregation of normal distributions from different strata with different means and standard deviations (Antle and Validivia, 2011).

Once an appropriate stratification has been undertaken, the system 1 state and system 2 states are characterized. System 1 is the farming system currently in place (the baseline or control in an experimental design) and is characterized empirically with observational data. In the present analysis, this is achieved based on the results of the farming household survey described in section below. Subsystems are then defined according to types of cropping and livestock systems (and aquaculture where present), and the activities within each subsystem. These include crop types, rotation and intercrops; species of livestock and types of livestock products, and methods and weights for aggregating livestock species (Antle et al., 2015). The types of farming systems represented in this analysis are annual and perennial cropping systems, and livestock.

Basic data required for model set up, for both systems 1 and 2, include the price of output for each activity ($/q/t), the yield of the activity (y/ha/t), variable production cost of the activity ($/ha/time) and the fixed cost for each activity ($/ha/time). A discount factor is used in model parameterization to convert fixed costs into annuity values. Based on this data, the net returns for system 1 are calculated as the summation of the net returns for each subsystem. Similarly, net returns for system 2 are calculated as the sum of the net returns for each subsystem, less the costs associated with switching from system 1 to 2 adjusted by the annuity factor. The opportunity cost therefore is the difference between the net returns from system 1 and 2 (Antle and Validivia, 2011).

System 2 represents the new state (the treatment group in an experimental design) which is characterized based on a scientific understanding of how improved technologies would affect productivity and other farm characteristics such as types of crops grown and input use. As discussed in the literature review, a core challenge of ex-post or retrospective economic impact evaluation is in the identification of a valid counterfactual which represents the outcomes that would have been observed if farms had not adopted system 2. In ex-ante analysis or forward looking assessments, the main challenge is in characterizing system 2 since its outcomes cannot be observed. This is referred to the system 2 problem which is similar to the problem of obtaining unbiased estimate of treatment effects from observational experiments (Antle and Validivia, 2011, Antle et al., 2014).

There are three main approaches to generating estimates of model parameters for the system 2 state. Extrapolation methods assume that there is a stable relationship between observable covariates and the parameters to be estimated; in the environmental economics literature, this is known as benefits transfer. Process-based crop/livestock/aquaculture growth models may also be used to construct the system 2 state given the relevant data is available for the area in question. Economic engineering or expert data is an approach that uses expert opinion to modify components of system 1 to construct system 2; in this case, system 2 is similar to system 1 though with some simple variations of that system (Antle et al., 2014).

Following stratification and the characterization of systems 1 and 2, variances of each subsystem are calculated next. For system 1, first the variance for each activity is calculated, then the correlation coefficient between activities in each subsystem. The standard deviation for the subsystem is taken as the sum of the square of the variance of the crop activity, the livestock activity and the aquaculture activity. For system 2, first the variance for each activity is calculated, then the correlation coefficient between activities in each subsystem is calculated. The standard deviation for the subsystem is taken as the sum of the square of the variance of the crop activity, the livestock activity and the aquaculture activity plus the variance of the annualized fixed costs required to shift from system 1 to system 2. The variance of the opportunity cost is calculated as the variance of system 1 plus the variance of system 2, minus two times the product of the standard deviation of system 1, system 2 and the correlation of returns between systems 1 and 2 (Antle and Validivia, 2011). Finally, impact indicators or outcome variables are defined which may be economic, environmental and social, depending on the objectives of the analysis (Antle et al., 2015, Antle et al., 2014, Antle, 2011). Once these variables are calculated and outcome indicators defined, the model is ready to be implemented.

The mechanics of TOA-MD are as follows. The adoption of technology in a population results in the creation of two sub-populations comprised of non-adopters and adopters of the technology represented by system 2. In TOA-MD, the decision to adopt can be structured as a maximization problem where profit maximizing farmers choose agricultural practices and systems which maximize their expected returns.

The opportunity cost of adoption may be defined as ω = v1 - v2.

Where:

* v1 represents economic returns per unit area per unit time for system 1, and;
* v2 represents economic returns per unit area per unit time for system 2.

When ω < 0, farmers are better off when they adopt system 2, and;

When ω > 0, farmers are worse off when they adopt system 2.

Opportunity cost varies across the landscape and population as in Figure A1 where ω < 0 represents adopters in the population. Agent behavior and the decision to adopt a new technology are based on many variables such as constraints on access to technology or credit, attitudes or cultural norms and policies that create incentives or disincentives for adoption. To represent these behavioral characteristics, an adoption threshold may be specified such that farmers choose system 2 if ω < *a* where *a* is the adoption threshold. Where a = 0, farmers follow the opportunity cost criterion. Where *a* is not equal to zero, this parameter represents an implicit cost or benefit perceived by farmers to be associated with adoption.

Outcome distributions are related to the system choice while impact indicators are based both on system choice and outcome distributions. A heterogeneous population of farms employing a production system of crops and livestock may be characterized by a joint distribution of economic, environmental and social outcomes which arise from interactions of these variables at the parcel, farm, household and population level (Antle et al., 2014). The current joint distribution of outcomes is represented by the system 1 observable state of nature. The alternative system, system 2 represents the state of nature that is out of sample and whose parametrization is the object of characterization through experimentation, modelling, benefit transfer and/or expert consultation.

Figure A1. Hypothetical distribution of opportunity cost of adoption. Source: Author’s own elaboration.

If the entire population of farmers switched from system 1 to system 2, a new outcome distribution would arise. However, in reality, only a subset of the population will tend to shift and therefore the result is a combination of outcome distributions based on both systems 1 and 2. Opportunity cost is the key concept that takes into account farmer behavior and self-selection.

ω

0

ϕ(ω)

100%

r(2)

The adoption curve is the area under the distribution ϕ(ω)

Figure A2. Distribution of opportunity cost and adoption curve; Source: Antle and Valdivia (2011).

Figure A2 describes graphically how the distribution function of opportunity costs is interpreted as the adoption curve for many farms. Note that each lightly shaded bar represents the opportunity cost of a group of individual farms. The adoption curve represents the area under the distribution of opportunity cost, and; the actual adoption rate when *a* = 0 is the point at which the adoption curve crosses the X axis. In figure A2, this occurs at an adoption rate of about 35%.

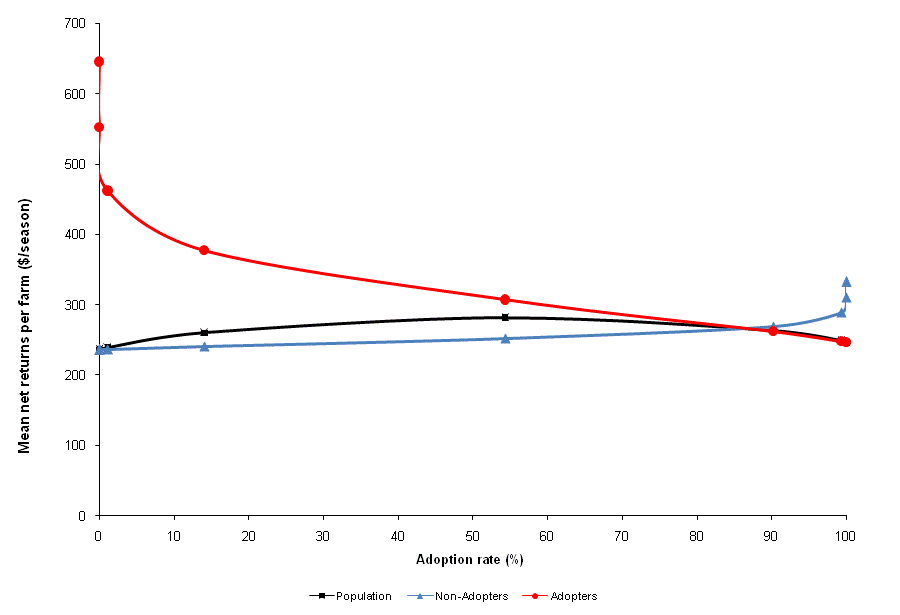


Figure A3. Adoption rate and relationship with net farming returns for the population, non-adopters and adopters. Source: Antle and Valdivia (2011).

Economic, environmental and social outcomes are jointly distributed with opportunity cost in the population. Following self-selection into adopter and non-adopter groups, each group has a different distribution for each outcome while the relationship between adoption, outcomes and impacts depends on correlations between opportunity costs and outcomes. Figure A3 depicts this relationship where economic outcomes that are positively related to net returns reach a maximum in the aggregate population at the predicted adoption rate, which in Figure A3 is a rate of 54%.

In the present application of TOA-MD, system 1 was characterized through a survey of farming households conducted during Program design. The characterization of system 2 was achieved through a preliminary analysis of potential lines of research to be undertaken by the agricultural research centers, a review of the literature, and the extrapolation of productivity and cost data from the relevant literature. What follows is a brief overview of the farming household survey and first results from the assessment of potential lines of research for the agricultural research centers.

# Appendix B. Basic data requirements for ex-ante economic evaluation

The World Bank (2000) outlines the basic data requirements for ex-ante analysis of agricultural research and extension programs. Following World Bank (2000, p. 15/16) research related data include:

|  |  |
| --- | --- |
| **Program data** | **Market data** |
| 1. Technology packages developed by the research program; | 1. Quantity of commodities produced and consumed; |
| 2. Expected change in yield; | 2. Prices received in sale and prices paid; |
| 3. Expected change in input costs; | 3. Exogenous output growth rate, which is the anticipated proportional change in output not due to research in each year (e.g. growth rate of area plus growth rate of yield not associated with the new research program); |
| 4. Probability of positive research outcome; | 4. Discount rate; |
| 5. Expected research and adoption lag; | 5. Three to four years of price and quantity data; |
| 6. Adoption path which is the time between first and full adoption; | 6. Prices and quantities of exports and imports, and exchange rates, and; |
| 7. Adoption ceiling, the maximum proportion of farmers expected to adopt the new technology; | 7. Population and income growth, and; information on government policy and other relevant market interventions over the period of analysis. |
| 8. The period of time over which the technology will generate full benefits; |  |
| 9. Depreciation factor- the rate at which the benefits of the new technology will depreciate after full benefits achieved; |  |
| 10. Annual research expenditure, including both Program of Interest funding and other sources of funding, from the beginning of research to the time of the release of the technology; |  |
| 11. Annual extension expenditure related to the technology (often estimated as total extension expenditure among crop by relative area planted). |  |

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1. FAO’s estimate of acreage is based on the assumption that 52% of households cultivate 0.2 hectares per year. [↑](#footnote-ref-1)
2. A third stage of analysis is also proposed, but requires significant additional time to enable processing and stratification of the data. This stage of analysis involves calibration and simulations with the Multi-Dimensional Trade-Off Analysis model (TOA-MD). This approach is considered to hold promise for future ex-ante economic analysis of agricultural interventions and is described in Appendix A. The GY-L1060 team will continue working with the farming household survey data to effectively calibrate TOA-MD; one outcome of these efforts will be an IDB Working paper offering guidelines to ex-ante economic analysis of IDB-supported agricultural interventions. [↑](#footnote-ref-2)
3. For additional sources of data on current and potential bora bean yields, please see: [↑](#footnote-ref-3)
4. Chesney, P.E.K, Simpson, L.A., Cumberbatch, R.N., Homenauth, O., and Benjamin, F. 2010. Cowpea Yield Performance in an Alley Cropping Practice on an Acid Infertile Soil at Ebini, Guyana. *The Open Agriculture Journal,* (4), pp. 80-84. Retrieved from: <http://benthamopen.com/ABSTRACT/TOASJ-4-80>

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