POTENTIAL ECONOMIC IMPACT OF INTEGRATED THRIPS MANAGEMENT IN FRENCH BEAN AND TOMATO IN LOITOKITOK AND MWEA SUB – COUNTIES OF KENYA

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DECLARATION AND APPROVAL

DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other academic institution.

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DEDICATION

To God whose invisible footprints dot every page of this work. To my parents, Mr. and Mrs. Mujuka, who taught me the virtues of hard work, perseverance and the value of education. To my siblings, Peter my spouse, Shana and Mary our daughters, Emmanuel our son, and friends for their encouragement, inspiration, patience and understanding.

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ABSTRACT

In Kenya, thrips inflict nearly 60-80% and 80% yield loss in French bean and tomato, respectively. Management of thrips in horticulture is currently based on application of pesticides. In addition to increased environmental risks associated with pesticides, frequent use of these chemicals substantially increase production costs and pesticide resistance. Further, exports are limited due to non-compliance to Maximum Residue Levels (MRLs) in important consumer export countries especially the European Union (EU). International Centre of Insect Physiology and Ecology (ICIPE) and its partners are proposing the use of Integrated Pest Management (IPM) for the control and management of thrips and tospoviruses in Kenya. The Centre has developed effective control technologies against quarantine thrips on key vegetables like French beans, onions and tomatoes.

However, before the dissemination of the developed technologies, there is need to assess the potential economic impact of the use of IPM in the control of thrips in French beans, onions and tomatoes in Kenya. Currently, such information is lacking. As such the government cannot effectively promote the technology and donors and farmers also have no basis for deciding on whether or not to invest in the technology. The objectives of this study were twofold. The first one was to measure the static *ex ante* economic returns to research on integrated thrips management in Loitokitok and Mwea sub–counties of Kenya. In the second objective, the dynamic *ex ante* economic returns to research on integrated thrips management in Loitokitok and Mwea sub–counties of Kenya was measured.

Both primary and secondary data were used. Primary data were obtained from 300 farmers in Loitokitok and Mwea sub–counties of Kenya using a questionnaire. In addition, expert opinion was also sought from researchers and scientists from KALRO and extension workers from MOALF for information on several model parameters including expected yield increases, adoption rate, adoption lag, number of years to maximum adoption, success rate

and the depreciation rate. Secondary data were collected from ICIPE's work plans and budgets for project costs and cost of IPM packages, journal articles for information on model parameters including elasticity of supply and demand for French beans and tomatoes and finally published literature from MOALF and HCDA provided information on yield and prices of French bean and tomatoes.

The economic surplus model was employed to measure the potential benefits of the IPM thrips technology research and development (R&D). Project costs and costs of adoption formed the cost stream. The benefit: cost ratio (BCR), the Net Present Value (NPV) and the Internal Rate of Return (IRR) were calculated using the Cost-Benefit Analysis (CBA) framework. Assuming a conservative adoption rate of 1% and a 10% discount rate for the base deterministic scenario, the NPV of the research was estimated at $ 4.8 million, with an IRR of 31% and a BCR of 4:1. Sensitivity analyses were undertaken to assess the effect of different discount rates and adoption levels on the NPV, IRR and BCR. The results showed that predicted returns to investment were sensitive to changes in the levels of adoption. The project seemed worthwhile at lower discount rates than at higher discount rates. Lower discount rates imply that the cost of capital is cheaper, thus favoring investment in the technology.

Risk analysis or probability weighted sensitivity analysis was carried out on NPV using the Monte Carlo simulation. The software @Risk was used in this regard at 10,000 iterations. The possible NPVs ranged from $63.16 million to $66.6 million. Since the possible range of NPV was positive, the probability of having negative NPV was excluded implying that there was no risk associated with implementation of this project. The results show that investment in IPM thrips technology is both financially viable and would lead to Pareto-efficient social welfare maximizing outcomes. It is therefore worth considering.

Based on the positive potential return on investments, efforts to promote the adoption of IPM thrips are encouraged to ensure more efficient production and greater economic rewards for the farmer and the country as a whole.

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ABBREVIATIONS AND ACRONYMS

ANOVA	:	Analysis of Variance
AVRDC	:	The World Vegetable Center, Taiwan
BCR	:	Benefit – Cost Ratio
BFT	:	Bean Flower Thrips
BMZ	:	German Federal Ministry for Economic Cooperation and Development
CBA	:	Cost Benefit Analysis
CS	:	Consumer Surplus
DRIP	:	Dissertation Research Internship Program
EU	:	European Union
FAOSTAT	:	The FAO Statistical Database
GHA	:	Global Horticultural Assessment
GTZ	:	German Technical Cooperation
HCDA	:	Horticultural Crop Development Authority, Kenya
ICIPE	:	International Centre of Insect Physiology and Ecology
IPM	:	Integrated Pest Management
IRR	:	Internal Rate of Return
IYSV	:	Iris Yellow Spot Virus
KALRO	:	Kenya Agricultural and Livestock Research Organization
LICs	:	Low Income Countries
MOA	:	Ministry of Agriculture
MLU	:	Martin Luther Universität, Halle, Germany
MOALF	:	Ministry of Agriculture, Livestock and Fisheries
MRLs	:	Maximum Residue Levels
NAAIAP	:	National Accelerated Agricultural Inputs Access Program
NARL	:	National Agricultural Research Laboratories

NARS	:	National Agricultural Research and System
NSW DPI	:	New South Wales Department of Primary Industries
NPV	:	Net Present Value
OT	:	Onion Thrips
PRI	:	Plant Research International, The Netherland
R&D	:	Research and Development
SP – IPM	:	System – wide Program on Integrated Pest Management
SSA	:	Sub-Saharan Africa
TBCS	:	Treasury Board of Canada Secretariat
TSWV	:	Tomato Spotted Wilt Virus
UoH	:	Leibniz Universität Hannover (University of Hannover)
WFT	:	Western Flower Thrips
WSU	:	Washington State University

CHAPTER 1: INTRODUCTION

1.1 Background

It is increasingly recognized that in the developing world, nearly three billion people live on less than US$ 2 per day (AVRDC, 2004). Majority of this population are smallholder farmers producing staple food crops with little prospects of generating higher incomes. Hence, diversification into high-value horticulture is essential for increasing farm incomes, alleviating poverty and improving livelihoods (Dennings, 2007; Sanginga, 2010). In Kenya, smallholder farmers in high-value horticultural production earn six to twenty times more income than their counterpart staple maize growers (Gabre-Mahdin and Hagglade, 2003; Minot and Ngigi, 2003).

The horticultural sector is one of the fastest growing sub-sectors of agriculture in sub-Saharan African countries (HCDA, 2008). However, this growth is seriously affected by both abiotic (nutrient-poor, degraded, and often acidic soils) and biotic constraints such as pest and diseases, coupled with lack of adequate information on their management (GHA, 2005). In countries like Kenya, linking horticulture supply chains to lucrative export markets often sidelines smallholders mainly due to lack of capacity to comply with stringent international market export requirements (Okello *et al*., 2011).

Thrips are a major production constraint in French bean (*Phaseolus vulgaris*) and tomato. Thrips (also known as thunder flies, thunder bugs, storm flies, thunder blights and corn lice) are tiny (≤1mm), slender insects pests with fringed wings. They feed on a large variety of plants. About 5,000 thrips species have been described (Tipping, 2008). Thrips are pests of commercial importance due to the damage caused on crops such as destroying flowers or vegetables, discoloration and deformities which lead to reduced marketability of the crop.

To manage thrips on the target crops, majority of smallholder growers heavily depend on chemical pesticides with application rates reaching as high as 10-15 sprays per season for French beans and onion crops (Nderitu *et al*., 1997). Such high levels of pesticide use negatively affect humans, the environment, bio diversity and also lead to development of pesticide resistance among key thrips species. Further, excessive levels of pesticides leave harmful residues on the produce, which further affect compliance to permissible Maximum Residue Levels (MRLs) and hamper their export.

Integrated Pest Management (IPM) emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms. It is essential that the option that poses the least risks while maximizing benefits is needed and the strategy may include all components related to integrated pest management strategies (Wright *et al*., 2005). Hristovska (2009) studied the economic impacts of IPM in developing countries and found that the tomato IPM program in Albania, the plantain IPM program in Ecuador, and the tomato IPM program in Uganda resulted in Net Present Values (NPVs) of approximately $8 million, $7 million and $1 million, respectively. These results mean that all the programs were viable and that the tomato IPM program in Albania was more viable than the tomato IPM program in Ecuador and in Uganda.

The International Centre of Insect Physiology and Ecology (ICIPE), the World Vegetable Centre (AVRDC) under the System-wide Program on Integrated Pest Management (SP-IPM), Leibnitz University Hannover (UoH), Martin-Luther University (MLU), Plant Research International (PRI), Washington State University (WSU) and the National Agricultural Research and System (NARS) from Kenya, Uganda and Tanzania are proposing an IPM project to enhance food, nutritional security and income generation capacity of smallholders in Eastern Africa (Subramanian, 2011). This will be through implementation of ecologically sustainable IPM measures that are less reliant on synthetic pesticides for thrips. The project will focus on French bean, onion and tomato in the East African region. The project proposes several IPM strategies for thrips management as shown in Table 1.1. Table 1.1 shows ICIPE's proposed IPM strategies for thrips management in French bean and tomato in Loitokitok and Mwea sub-counties of Kenya.

Table 1. : Proposed IPM strategies for thrips management in French bean and tomato in Loitokitok and Mwea sub-counties of Kenya

No.	Proposed IPM strategies French bean	No.	Proposed IPM strategies Tomato
1.	French bean and baby corn (Ratio 1:8)	1.	Pesticides alone (Lambda-Cyhalothrin) @ weekly spray
2.	Pesticides alone (Lambda-Cyhalothrin) @ weekly spray	2.	Pesticides alone (Confidor) @ weekly spray
3.	Pesticides alone (Confidor) @ weekly spray	3.	Biopesticide spraying alone @ weekly spray
4.	Biopesticide spray alone @ weekly spray	4.	Use of coloured sticky traps of monitoring and spraying of Lambda Cyhalothrin
5.	Botanicals Pyrethrum spray@ weekly spray	5.	Use of coloured sticky traps of monitoring and spraying of Imidacloprid
6.	Use of coloured sticky traps of monitoring and spraying of LambaCyhalothrin	6.	Use of coloured sticky traps of monitoring and spraying of biopesticide
7.	Use of coloured sticky traps of monitoring and spraying of Confidor	7.	Use of coloured sticky traps, LUREM and spraying of LamdaCyhalothrin
8.	Use of coloured sticky traps of monitoring and spraying of biopesticide	8.	Use of coloured sticky traps, LUREM and spraying of biopesticide
9	Use of colouredsticky traps, LUREM and spraying of LamdaCyhalothrin		
10.	Use of coloured sticky traps, LUREM and spraying of biopesticide		

Source: ICIPE (2013)

This study focused on the IPM strategy comprising of use of coloured sticky traps, kairomonal attractants that have lures for attracting thrips and application of bio pesticides as the main components. Muvea (2011) studied the potential of coloured sticky traps and kairomonal attractants in the management of thrips on tomato and French beans in Kenya. The author found that blue sticky traps caught 13.24 - 59.12 and 22.07 – 29.31 times more than clear traps on tomato and French bean respectively. Addition of kairomonal attractants increased percentage of thrips captured by 0.87% – 66.97% and 29.6% - 158.4% on tomato and French bean, respectively. The current study measured the potential economic impact of use of coloured sticky traps, kairomonal attractants and bio pesticides in French bean and tomato in Loitokitok and Mwea sub-counties of Kenya to generate information that will guide research planning, priority setting, dissemination and investment decisions for new IPM technologies.

Focusing on costs and benefits, economists distinguish between two broad types of economic evaluations namely, *ex ante* and *ex post*. An *ex ante* impact evaluation attempts to measure the intended impacts of proposed interventions before their implementation. (Anandajayasekeram and Martella, 1999). *Ex ante* studies are based on projections made by researchers, extension workers and social scientists regarding yield, likely success rate and adoption of the new technology (Debass, 2000). *Ex post* assessments, on the other hand, take place after a project has been completed in order to evaluate whether or not the project was value for money to both funders and beneficiaries (Debass, 2000).

1.2 Statement of the problem

French bean, *Phaseolus vulgaris*, is widely cultivated by both the small and large-scale farmers across the Central, Eastern, Western and Coast provinces of Kenya (Onkoba, 2002). The crop constitutes nearly 20% by volume and 10% by value of all fresh horticultural exports (HCDA, 2008) and ranks second after roses (Nderitu *et al*., 2007). On French beans, a complex of four thrips species (Western Flower Thrips (WFT), Bean Flower Thrips (BFT), *F. Schultzei*and *H. adolfifriderici*) inflict nearly 60-80% yield losses (Nyasani *et al*., 2010). The insects attack flowers leading to abscission and poor yield and damaged pods are often malformed and rejected by export market (Nderitu *et al.*, 2001).

Tomato (*Lycopersiconesculentum*), is the most important horticultural crop cultivated on over 4 million ha worldwide (FAOSTAT, 2009; Brown *et al*., 2005). In Kenya, tomato are cultivated in diverse agro-ecological zones from the coastal zones of Kilifi, across the central mid and high altitude zones and the humid zones of Western and Nyanza provinces on over 18,000ha and output of over 500,000Mt (HCDA, 2008). The damage by thrips on tomato is often compounded by Tomato Spotted Wilt Virus (TSWV) vectored by WFT. In Kenya, WFT causes up to 80% yield loss in tomato (Wangai *et al*., 2001).

To manage thrips in French beans and tomato, farmers rely extensively on synthetic pyrethroid applications especially lambda-cyhalothrin (Nderitu *et al*., 2001; Kasina *et al*., 2006). These insecticides have been shown to possess minimal efficacy due to high levels of resistance in thrips species such as WFT and BFT (Nderitu *et al*., 2001). In addition to increased environmental risks associated with pesticides, frequent use of these chemicals substantially increase production costs, pesticide resistance and limit export due to non-compliance to MRLs in important consumer export countries especially the EU (Burkett-Cadena *et al*., 2008).

Thrips management methods that are based on the use of synthetic insecticides have often failed because of their cryptic feeding behaviour, rapid multiplication, development of insecticide resistance and contribution to non-compliance with MRLs (Immaraju *et al*., 1992). Managing thrips is further complicated by lack of natural parasites and the presence of numerous other host plants on which the pest thrives (Brewster, 1994). Hence, the use of IPM strategies with less reliance on synthetic pesticides has been strongly advocated for management of thrips and tospoviruses vectored by thrips (Gillett-Kaufmann *et al*., 2009).

The ICIPE and its partners are proposing the use of IPM for the control and management of thrips and tospoviruses in Kenya. The project has developed effective control technologies against quarantine thrips on key vegetables like French beans, onions and tomato (Subramanian, 2011). However, before the dissemination of the developed technologies, there is need to assess the potential economic impact of the use of IPM in the control of thrips in selected vegetables such as French beans, onions and tomato in Kenya in order to guide investment in further research and development and eventual dissemination. To date there is virtually no information on potential economic impact of research investment in IPM technology for thrips control in French beans and tomato in Kenya and hence this study.

1.3. Objectives of the study

The overall objective of this study was to assess the potential economic impact of integrated thrips management on French beans and tomato in Loitoktok and Mwea sub-counties of Kenya. The specific objectives of the study were:

1. To measure the static *ex ante* economic returns to research on integrated thrips management in Loitokitok and Mwea sub –counties of Kenya.

2. To measure the dynamic *ex ante* economic returns to research on integrated thrips management in Loitoktok and Mwea sub–counties of Kenya.

1.4. Hypotheses of the study

The study hypothesized that:

1. There is no static potential economic return to research initiated by ICIPE on integrated thrips management in French beans and tomatoes in Loitoktok and Mwea sub–counties of Kenya.

2. There is no dynamic potential economic return to research initiated by ICIPE on integrated thrips management in French beans and tomatoes in Loitoktok and Mwea sub–counties of Kenya.

1.5. Justification of the study

As resources for agricultural research and development become increasingly scarce world-wide (Anderson *et al*., 1994), *ex ante* assessments of the potential benefits and costs of research investments are now being used by national and international research centers to aid in priority setting and resource allocation (Kristjanson, 1997; Kelly *et al*., 1995). With a wide range of research and development approaches to choose from, donors are interested in seeing analyses of the potential impact of various types of investment. An *ex ante* analysis addresses issues that ensure the research is well targeted and the path from research station to the farmer is clear (Kristjanson and Zerbini, 1999). Policy makers will benefit from the findings in deciding on whether or not to promote integrated thrips and tospoviruses management. Results of this study will guide ICIPE in priority setting and resource allocation of thrips IPM technology development projects. Finally, this study will reveal impact of future scenarios on the potential economic impact of uptake of integrated thrips management in Loitokitok and Mwea sub-counties of Kenya.

The main contribution of this study is the extensive review of literature on the economic theory underpinning *ex ante* evaluation and the incorporation of the probability weighted sensitivity analysis in projected cost and benefit of investment in agricultural research in order to analyze the robustness and model sensitivity to the underlying parameter estimates and assumptions.

1.6. Organization of the thesis

The study is divided into four additional chapters. In Chapter Two, the literature is reviewed, providing an overview of integrated pest management and economic evaluations. After theoretical review, empirical review follows with a focus on studies on economic evaluation and past studies that have employed the economic surplus model. In Chapter Three, the methodology of the study is discussed in detail. Chapter Four presents results of the study while chapter five presents a summary of the study, conclusions and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Integrated Pest Management

The IPM is a strategy that draws on a range of management tools with the goal of using the least ecologically disruptive techniques to manage pests to economically acceptable levels (McDougall, 2003). The distinguishing features of an IPM strategy are the use of knowledge about the biology of pests and their interaction with their natural enemies, knowledge of cultural and chemical control strategies, monitoring of pests and beneficial populations to allow growers to make profitable pest management decisions.

The term IPM refers to a crop protection approach that is centred on local farmer needs that are sustainable, appropriate, environmentally safe and economic to use (GOK, 2009). IPM is a diverse mix of approaches to manage pests and keep them below damaging levels, using control options that range from cultural practices to chemical pesticides (Sorby *et al*., 2003). According to Blake *et al*. (2007), IPM refers to the intellectual selection and use of pest control actions that ensure favourable economic, ecological and sociological consequences.

The IPM has been hailed as a means to enhance agricultural profits and human living conditions while reducing pesticide risks to human health and the natural environment. During the past two decades, government programs in the United States and elsewhere have sought to encourage adoption of IPM methods. These programs have expanded recently in tandem with policies designed to reduce human exposure to pesticide risks (notably the U.S. Federal Insecticide, Fungicide and Rodenticide Act as amended in 1988 and the Food Quality Protection Act of 1996). In 1993, Vice President Al Gore pledged that the United States would achieve adoption of IPM on 75% of its agricultural land by the year 2000 (Swinton and Williams, 1998).

2.2 Review of theoretical literature

Alston *et al*. (1995) provide an extensive review of models used in the economic evaluation of agricultural research at the project level. They discuss both the economic surplus analysis approach and econometric methods used in estimating the economic benefits of research on new agricultural technologies. Econometric estimation is suitable for *ex post* studies where the effect of past investments in research can be estimated using data on inputs, outputs, and research expenditure. It employs a production function, cost function or a total productivity analysis to estimate the change in productivity due to investment in research. Its main advantage is that it provides a means of statistically isolating the effects of research programs. The main constraint on the wider application of econometric approaches in developing countries is data availability and quality (Maredia *et al*., 2000).

The economic surplus method is used in both *ex ante* and *ex post* studies and is one of the most commonly used. It is based on the premise that resources for agricultural research are scarce and must therefore be allocated efficiently (Debass, 2000). Its goal is to estimate the aggregate social net benefits of a research undertaking. Figure 2.1 illustrates the basic economic surplus model.

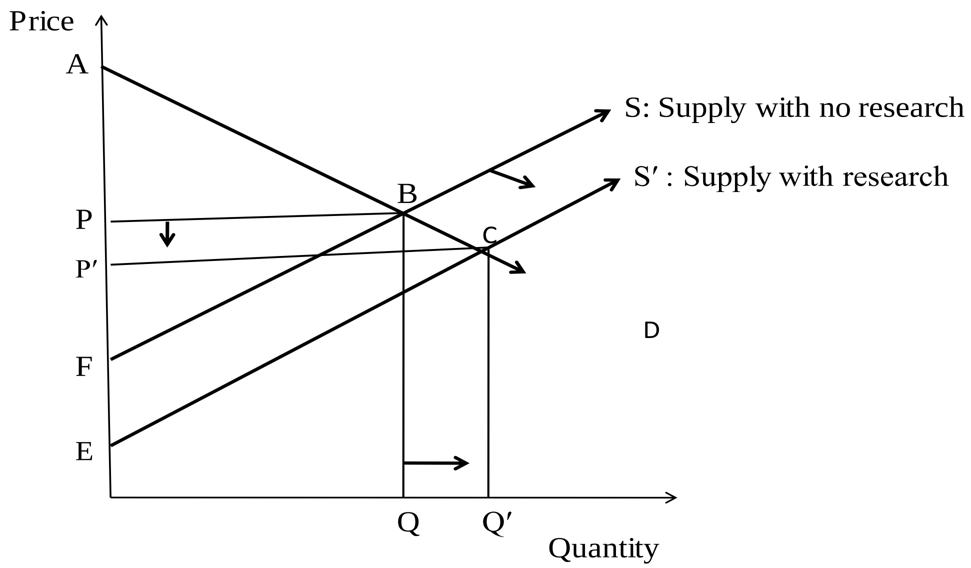

Figure 2. 1: Illustration of the economic surplus with and without research
Source: Adapted from Alston *et al*. (1995)

where

D = Demand function for tomato

S= Supply function for tomato before research-induced change.

$S^{'}$ = Supply function for tomato after research-induced change

P= Initial equilibrium price

$P^{'}$ = Price after research induced-change

Q= Initial equilibrium quantity

$Q^{'}$ = Quantity after research induced change

EFBC= Change in total surplus

Application of research output in production process is a supply shifter because of either increased productivity or reduced cost of production. Research leads to a right-ward shift of the supply curve (from S to S′) implying an increase in the quantity supplied from Q to Q′.

Increased supply means a fall in price from P to P′, which leads to an increase in consumer surplus from PAB to P′AC. Consumer surplus is given by the area below the demand curve above the price line, such as the area PAB (Alston *et al*., 1995).

Producers lose their surplus of FPB but gain EP′C due to increased demand from Q to Q′. Producer surplus is given by the area above the supply curve below the price line such as the area FPB. The impact on producer surplus depends on the elasticity of demand and supply curves. The benefits of an agricultural research undertaking to the society are given by the sum of the net gain in consumer and producer surplus equal to the area EFBC (Alston *et al*., 1995).

Estimation of the economic surplus requires information on productivity increase generated by a given research activity, equilibrium output price, adoption rate and costs, timeframe between research and adoption and price elasticity of supply and demand (Affognon, 2010). The economic surplus is then utilized together with the research costs to calculate the BCR, NPV or the internal rate of return (IRR), which is the rate of interest for which NPV is equal to zero (Alston *et al*., 1995).

2.3Review of empirical literature

2.3.1 Studies on economic evaluation

Several empirical studies apply economic surplus in evaluating impacts stemming from new agricultural technologies. These studies treat specific new technology evaluations in diverse market contexts.

Gajanana *et al*. (2006) assessed the economic impact of adoption of IPM in tomato in India. The authors employed partial budgeting technique and found that the IPM technology was viable as the yield on IPM farms was higher by about 46 %, cost of cultivation reduced by about 21 % and the net returns were higher by 119 %.

MacLeod *et al*. (2004) assessed the potential economic impact of *Thrips palmi* on horticulture in England and the significance of a successful eradication campaign. The authors estimated the NPV of the economic impact of *T. palmi* over 10 years to be between £16.9 and £19.6M depending upon the rate of pest spread. Without loss of exports, impacts fell to between £0.6 and £3.3M over 10 years. The BCRs for eradicating the outbreak and maintaining an exclusion policy towards *T. palmi* ranged from 4:1 to 19:1 if there is no loss of exports and from 95:1 to 110:1 if significant export losses did result from *T. palmi* establishment.

Debass (2000) used partial budgeting and *ex ante* economic surplus analysis to estimate the aggregate benefits of the IPM strategies in Bangladesh and Uganda. The study provided evidence that the welfare benefits were shared both by consumers and producers, and IPM strategies were more profitable than farmer practices. The NPV and the IRR of the cabbage and brinjal IPM in Bangladesh were $29 million and 684% respectively. The NPV and the IRR of the maize and beans IPM in Uganda were $26 million and 696% respectively.

2.3.2 Past studies that have employed the economic surplus model

Affognon (2010) estimated the potential impact of BMZ investments in trypanocide resistance research using the economic surplus model and found a deterministic estimate of the NPV of € 62 million, with an IRR of 45%, and a BCR of 48:1. Kostandini *et al*. (2006) applied the economic surplus model under imperfect competition to show the potentials of biopharming by looking at the transgenic tobacco case. Their results indicated that in a market with patent rights only the innovating firm will benefit, while consumer benefits are unlikely.

Song and Swinton (2008) evaluated the potential economic returns to IPM research and outreach for soybean aphid in the United States of America. They employed the economic surplus model and assumed a closed economy. Their research found that gradual adoption of action threshold (AT)-based IPM over the 15 years since soybean aphid IPM research began in 2003 generated a projected economic net benefit of $1.3 billion, for an IRR of 140%. Lower and upper bound sensitivity analysis bracketed the estimated net benefit to U.S. consumers and soybean growers in the range of $0.6 to 2.6 billion in 2005 dollars.

Orr *et al*. (2008) evaluated the economic, environmental and social impacts of New South Wales Department of Primary Industries (NSW DPI) Investments in IPM Research in Lettuce in Australia. They employed the economic surplus model and estimated the benefit-cost ratio (BCR), the net present value (NPV) and the internal rate of return (IRR) of NSW DPI lettuce IPM research from the year 1999 up to the year 2006 at 1.7, $1.63 million and 46% respectively. When research benefits and costs were extended to the year 2020 the BCR was 2, the NPV was $5.4 million and the IRR was 48%.

Hareau *et al*. (2006) carried out *ex ante* evaluation of the economic impact of herbicide resistant transgenic rice in Uruguay. They used a stochastic simulation technique to estimate how benefits vary with changes in technology, yield, costs, and adoption parameters. They found that the benefit for the multinational company that would develop the technology was $0.55 million. In their study of the potential economic returns to research on genetic enhancement of sorghum and millet residues fed to ruminants, Kristjanson and Zerbini (1999) employed the economic surplus model. The authors estimated the net present value of the research between 42 and 208 million USD. Prediction of rate of return to the research investment varied from 28% to 43% with corresponding benefit: cost ratios of 15-69:1.

Kristjanson *et al*. (1999) used the economic surplus model to measure potential returns to the International Livestock Research Institute’s research on trypanosomosis vaccine. They estimated the NPV of the vaccine research at US$ 288 million, with an IRR of 33%, and a BCR of 34:1. That would be the case given an adoption period of 12 years, a maximum adoption rate of 30%, a discount rate of 5%, and a 30% probability of the research being successful within10 years. These are just a few examples of the many studies which have used the economic surplus analysis to evaluate impacts of agricultural research. This is due to data limitations on the econometric approach (Maredia *et al*., 2000).

2.4 Summary

While the literature reviewed herein focused exclusively on expected profits, the novelty of this study is that it considered profitability risk. Further, these studies employed the economic surplus model to assess the economic impact assuming a closed economy. This study employed the economic surplus model in assessing the potential economic impact of IPM assuming an open economy in the case of French beans and a closed economy in the case of tomato. The assumption of an open economy in the case of French beans was based on the fact that French beans are primarily grown for export with a small quantity consumed in the domestic market (HCDA, 2012). However, tomato are important vegetables grown for domestic consumption (HCDA, 2008), hence the closed economy assumption. The IPM is also dynamic and the researcher has come up with combination of different components of IPM that have neither been tried elsewhere, nor their potential economic benefit measured, hence this study.

CHAPTER 3: METHODOLOGY

3.1Conceptual framework

Figure 3.1 illustrates the *ex ante* technology impact assessment process. The process of potential economic evaluation starts with researchers and other stakeholders identifying commodities (such as French beans and tomatoes) of interest and the constraints hindering the realization of optimal yield. The researchers then embark on technology development. Possible technical solutions such as IPM are then suggested. This could involve on-station development of pest management practices, followed by on-farm testing with the farmers. This is useful in order to evaluate the technology in a wider range of conditions than is available on-station. Further, it is important for obtaining input-output data for cost–benefit analysis.

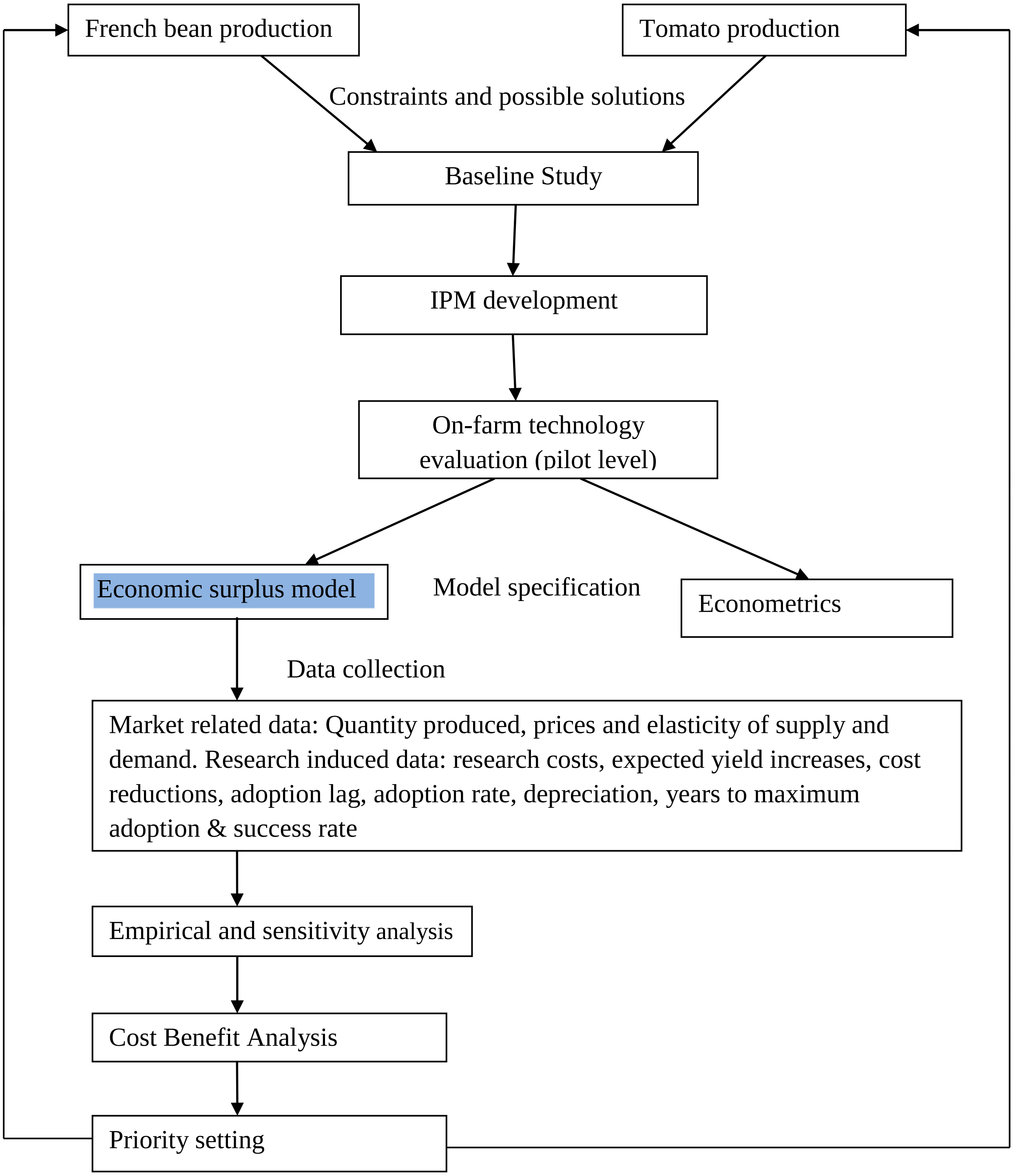

Figure 3. 1: A schematic illustration of an *ex ante* technology impact assessment process

Source: Author

The next step is model specification to achieve the stated objective such as measuring the potential economic impact of IPM in French beans and tomatoes in Loitokitok and Mwea sub-counties. Advantages and disadvantages of all possible models guide the selection of the relevant model (Alston *et al*., 1995). Relevant data are then collected followed by empirical analysis. Due to the inherent risk associated with *ex ante* assessments, sensitivity analysis is performed. Finally, the results are used to prioritize alternative investments.

3.2Theoretical Framework

This study is anchored on welfare economics which is based on Pareto efficiency and compensation principles. The Pareto efficiency criterion is a technique for comparing or ranking alternative states of the economy. Pareto efficiency is a state of allocation of resources in which it is impossible to make any one individual better off without making at least one individual worse off. If this is the case, a movement from state A to state B represents a Pareto improvement, or state B is Pareto superior to state A (Pareto, 1896). If society finds itself in a position from which there is no feasible Pareto improvement, such a state is called a Pareto optimum (Pareto, 1896).

If the economy is not at a Pareto optimum, there is some inefficiency in the system because when output is divisible, it is always theoretically possible to make everyone better off in moving from a Pareto-inferior position to a Pareto-superior position (Pareto, 1896). Hence, Pareto optimal states are also referred to as Pareto-efficient states, and the Pareto criterion is referred to as an efficiency criterion (Pareto, 1896). States where one person is made better off and another is made worse off are referred to as Pareto-non comparable states. According to Thurow (1980), by the Pareto criterion, a policy change is socially desirable if, by the change, everyone can be made better off, or at least some are made better off, while no one is made worse off. If there is anyone who loses, then the criterion is not met (Thurow, 1980). The author contends that many good projects do not get underway simply because project managers are unwilling to pay compensation to those who would actually be made worse off.

According to Kaldor (1939) and Hicks (1939), the compensation principle is stated in terms of potential compensation rather than actual compensation because the payment of compensation involves a value judgment. The principle states that, state B is preferred to state A if, in making the move from state A to state B, the gainers can compensate the losers such that at least one person is better off and no one is worse off (Kaldor, 1939). Such states are sometimes called potentially Pareto preferred states (Hicks, 1939). The compensation principle can be used to compare different distributions of different output bundles.

Figure 3.2 shows the compensation principle and the welfare function. Following Just *et al*. (2004), the indifference curve *C* corresponds to production at *OB* (such as production without IPM) and the distribution at point *a*. Similarly, with production at O_B^*(such as production with IPM), the Scitovsky curve corresponding to distribution at point *b* is *C**. At point *b*, one individual is worse off than at point *a*, and the other individual is better off. However, potential gains are possible in the move from point *a* to point *b* because the amount the loser loses is less than what the gainer gains. Potential gains are clear because production at O_B^* can be distributed to keep welfare the same as at point *a* by moving along the Scitovsky indifference curve *C* to point *f*. By so doing, *fh* of *q*2 and *fg* of *q*1 are left over. Thus, if the compensation principle is used as a policy criterion, the move would be made (even though at point *b* one of the individuals may be actually worse off than at point *a*.

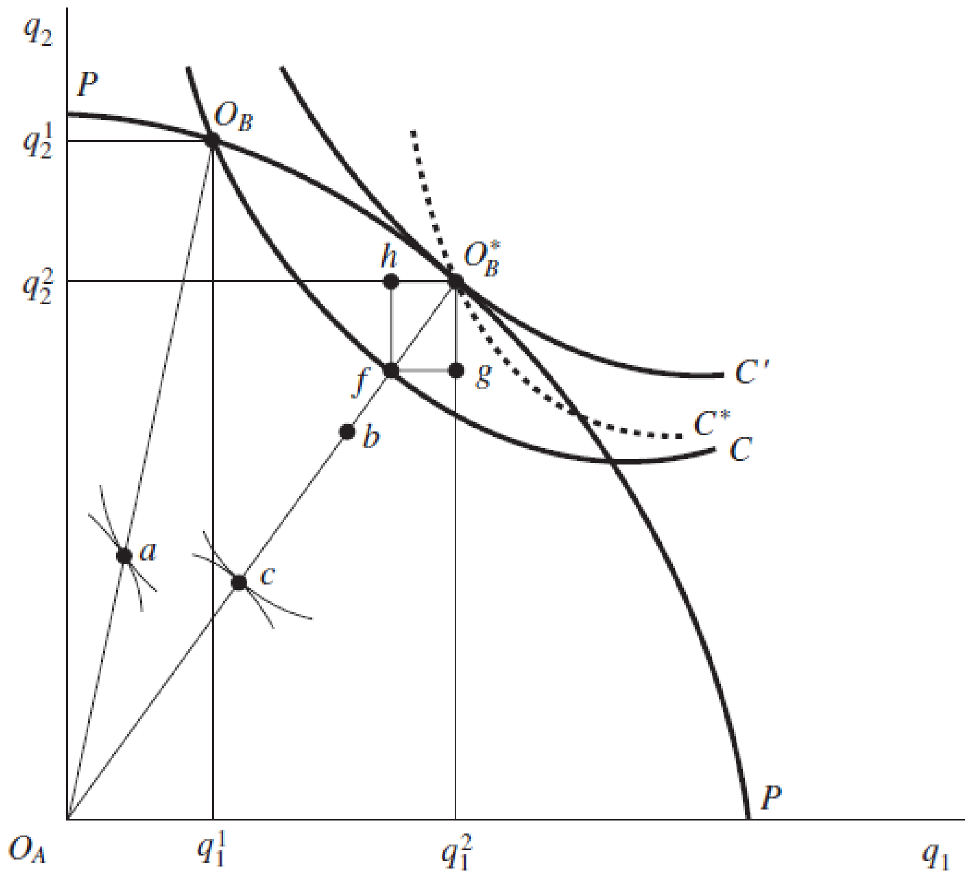

Figure 3.2: The compensation principle and the welfare function

Source: Adapted from Just *et al*. (2004)

Just *et al*. (2004) compare and contrast the compensation and the Pareto principle. They suggest that using the compensation principle with initial production bundle at *OB* and distribution at point *a*, a move to the production bundle at *OB** is supported regardless of the way it is actually distributed. Using the Pareto principle, however, the move is supported only if the actual distribution corresponds to moving along the Scitovsky curve *C* to point *f*, keeping the welfare of each individual constant and then dividing the excess of *fg* of good *q*1 and *fh* of good *q*2 among the two individuals in someway so that neither is worse off.

According to Just *et al*. (2004), the reason that production at *OB** is preferred to production at *OB*, in either case, is that the starting point with distribution at point *a* is a second-best state. The corresponding Scitovsky curve *C* is not tangent to the production possibility frontier *PP*.

Like the Pareto criterion, the compensation principle does not support a move away from a first-beststate such as production at *OB** with distribution point *c* corresponding to Scitovsky indifference curve *C′*. Thus, the compensation criterion, like the Pareto criterion, cannot be used to rank two first-best states. A movement from one to the other would not be supported regardless of which is used as a starting point. The compensation criterion, on the other hand, gives a means of comparing all pairs of second-best states and for comparing all second-best states with all first-best states (Just *et al*., 2004).

3.3 Empirical framework

The economic surplus framework can be used to measure the potential benefits of and returns to research or development efforts aimed at alleviating constraints. The economic surplus approach provides a relatively simple, flexible way to assess the value of research, by comparing the situations with and without it. The approach uses the concepts of supply, demand and equilibrium. Supply represents producers' production costs and demand represents consumers' consumption values (Alston *et al*., 1995). In this study, a partial-equilibrium comparative static model was used in the analysis following Kristjanson and Zerbini (1999) and Alston *et al*. (1995). In the case of tomatoes, a closed economy model was assumed because of the little international trade of tomato as a result of stringent international export requirements (HCDA, 2012).

The closed economy assumption is based on Keynesian theory. The theory assumes that a developed capitalist economy is a closed economy, where level of income and employment remain affected by the foreign trade (Keynes, 1964). Assuming a closed economy implies that the adoption of a cost-reducing or yield-enhancing technology increases the supply of a commodity such as tomato. In the case of French beans, on the other hand, Kenya was assumed to be a small exporting country and a model that encompasses international trade was explored. The open economy assumption was based on the new growth theory by

Dowrick (1997) whose three theoretical mechanisms suggest that the openness of national economies may have a profound, if ambiguous, impact upon their growth. This assumption means that price was pegged at the world market price.

The project's research activities as well as the adoption of resultant technologies was expected to increase the supply of the total output of tomato. The increase in supply was expected to reduce the consumer prices of tomatoes as well as reduce the production cost to producers following production theory as shown in Figure 3.3.

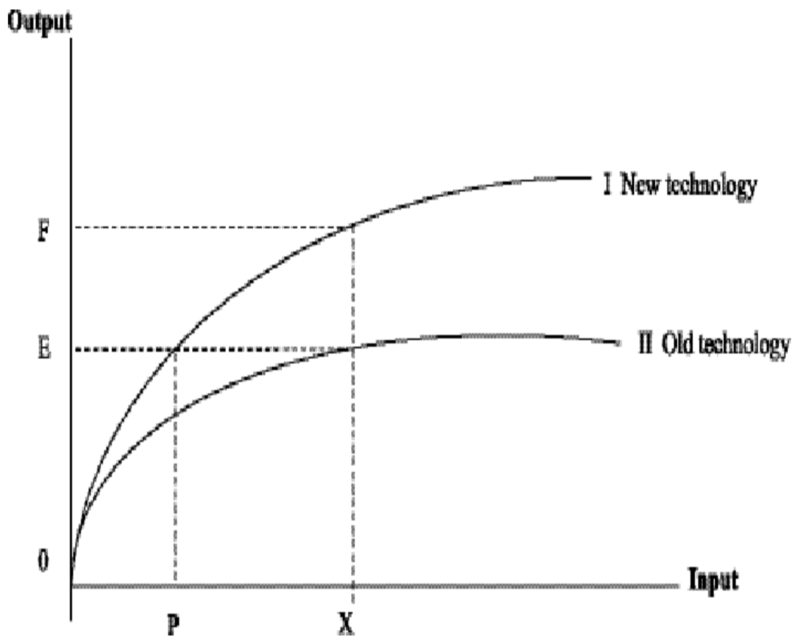

Figure 3.3: The nature of technological change

Source: Adopted from Heady (1952)

Technological improvement has two general properties. The first is the development of a new production function such that a greater output is achieved from a given input level (Debertin, 1986). Production function I represents production with new technology while production function II represents old technology. With the same input level, OX, output is increased from OE to OF because of the shift in the production function due to the new technology. Alternatively, the same output level, E, can be produced with a lower level of input (OP), due to the introduction of the new technology (Debertin, 1986). The second property is that the technological improvement must monetarily increase the discounted profits (or decrease losses) of the firm (Heady, 1952). The firm would never adopt an innovation if output were not increased from given resources, or if input decreased for a given output (Heady, 1952).

An economic surplus framework considers per unit cost reductions and price responses to research-induced quantity shifts and assesses the level and distribution of research benefits. The model shows to what extent research-induced reductions in per unit cost of production and in adoption by farmers, may reduce market prices (Norton and Dey, 1993).

Linear supply and demand curves with parallel shifts were assumed following Kristjanson and Zerbini (1999). When a parallel shift is used, the functional form is largely irrelevant and a linear model provides a good approximation to the true unknown functional form of supply and demand. The size and nature of the shift in the supply curve influence the distribution and total benefits. Total benefits from a parallel shift are almost twice those from a pivotal shift (Alston *et al*., 1995). Norton *et al*. (1992) suggest using a vertically parallel shift for simplicity and consistency in evaluating the different programs for different commodities. According to their study, producers always benefit from a parallel supply shift while they only benefit from a pivotal shift when demand is elastic. In this study, demand was assumed to be elastic, based on Bundi *et al*. (2013).

3.3.1 Cost benefit analysis

Cost Benefit Analysis (CBA) is an economic assessment tool. It identifies and quantifies all relevant costs and benefits and provides a consistent basis for the assessment of the impact of a specific project and for the comparison of alternative proposals (Boardman *et al*., 2001). By quantifying all costs and benefits in monetary terms and discounting, it is possible to determine the net benefits of a project or proposal (Affognon, 2010). These net benefits can then be used by decision-makers to quantitatively rank alternative proposals or to provide donors with information about the implications of using scarce economic resources. In this study, the cost-benefit analysis was used to assess the economic implications of ICIPE's investments in research on IPM. All costs associated with the project since inception were considered, as well as the cost of IPM to the farmers expected to adopt the technology based on expert opinion.

Once changes in economic surplus were projected over time, calculations of net present values (NPV), internal rates of return (IRR), benefit-cost ratios (BCR) and further sensitivity analyses that were helpful considering the *ex ante* nature of the evaluation were carried out. The benefits were the changes in total economic surplus calculated for each year for both French beans and tomatoes, while the costs were the expenditure related to developing the IPM technology, cost of extension, as well as the cost of adoption by the farmers. The surplus analysis takes into account discounting, since the sooner benefits occur the more they are worth (TBCS, 1998).

All the information on benefits and costs were collected and aggregated on an annual basis over the lifetime (16 years) of the technology to determine the annual streams of costs and benefits. The NPV, the IRR and the BCR all depended on similar information in the generation of benefits and costs associated with the technology over the 16 years.

Net Present Value (NPV)

Net present value (NPV) or net present worth (NPW) is the classic economic method of evaluating investments (Pandey, 2010). It computes present value by discounting a set of benefits and costs that occur through time, back to the beginning of the base year (t=0) as shown in equation 3.1. It assesses whether there is optimal allocation of resources among alternative investments.

$$NPV = \sum_{t=1}^{T} \frac{R_t - C_t}{(1+i)^t} \quad \text{…………………………….(3.1)}$$

where:

R_t = the return or benefit in year t

C_t = the cost in year t

i = the discount rate

The decision criterion when using the NPV is to accept an investment among alternatives when the NPV is positive. This implies that the firm will be earning a return greater than or equal to its required return or cost of capital (Mudida and Ngene, 2010). Such a firm would be said to be Pareto efficient. In the event that the NPVs of all investments are positive, the investment with the highest NPV is accepted. The project with the highest NPV will make the greatest contribution to the objective of wealth maximization of a firm (Ahuja, 2006).

Internal Rate of Return (IRR)

The internal rate of return (IRR) is defined as the interest rate where the NPV is equal to zero (Mudida and Ngene, 2010) as shown in equation 3.2.

$$\sum_{t=1}^{T} \frac{R_t - C_t}{(1+IRR)^t} = 0 \quad \text{…………………………….3.2}$$

It assesses the interest rate of an investment against the opportunity cost of capital. The decision criterion when using the IRR is to accept an investment if the IRR is higher than the opportunity cost of capital. This means that the chosen investment is expected to produce a higher return than the cost of financing the project (Mudida and Ngene, 2010). The exact IRR can be obtained through interpolation as shown in equation 3.3.

$$IRR = a + \left\{ \frac{A}{A-B} \times (b-a) \right\} \quad \text{………………………..(3.3)}$$

where:
a is the lower discount rate
A is NPV at the lower discount rate

b is the higher discount rate

B is the NPV at the higher discount rate

Benefit Cost Ratio (BCR)

The decision criterion when using the BCR is to accept an investment if the BCR is greater than or equal to one. This means that the discounted benefits are greater than the discounted costs (Pandey 2010). It assesses an investment's ability to recover initial costs.

On a purely theoretical basis, NPV is the better approach to capital budgeting as a result of several factors. Most important, the NPV measures how much wealth a project creates (or destroys if the NPV is negative) for shareholders (Gitman and Zutter, 2013). Given that the firm's objective is wealth maximization, the NPV approach has the clearest link to this objective and therefore is the gold standard for evaluating investment opportunities (Gitman and Zutter, 2013). In public investments, using the NPV assesses whether or not the investment is Pareto efficient so that no one is made better off while others become worse off due to the project.

This study assessed the potential economic returns to research on integrated thrips management in French beans and tomatoes. This was done with uncertain timing of benefits and adoption of knowledge and information generated from the research. It was thus important to carry out an analysis on the sensitivity of the results to some of the assumptions or estimates that were used in the economic surplus model.

3.3.2 Sensitivity analysis

Because economic evaluation is a predictive tool, it is difficult to determine accurately what a technology's benefits and costs will be in the future. Future values are difficult to predict and there will always be some uncertainty about the analysis results (Qaim, 1999). Therefore, the effects of different values should be investigated. One useful and simple way of gaining insight into the impact of uncertain outcomes is a sensitivity analysis. A sensitivity analysis is the comparison of outputs from a model, given certain changes in model structure or model input. It aims to ascertain how sensitive the model is to small changes in the information fed into it, based on its structure and assumptions (Qaim, 1999). This information can be invaluable, as (a) different level of acceptance (by the decision-makers and stakeholders) may be attached to different types of uncertainty, and (b) different uncertainties impact differently on the reliability, the robustness and the efficiency of the model and the overall framework.

Sensitivity analysis involves changing the value of one or more selected variables and calculating the resulting change in the NPV, BCR or IRR. The extent of change in the selected variable to test can be derived from post evaluation and other studies of similar projects (Alston *et al*., 1995).

Changes in variables can be assessed one at a time to identify the most sensitive one. Possible combinations can also be assessed. Sensitivity analysis should be applied to project items that are numerically large or for which there is considerable uncertainty (Qaim, 1999). To facilitate mitigating action, variation should be applied separately to underlying variables, not just to aggregate values (Qaim, 1999). Where the results are shown to be sensitive to the value of a variable that is uncertain, mitigating actions should be considered. This can include more investment in reliable information or redesigning questionnaire formats and methods to obtain accurate responses from researchers (Qaim, 1999). Following a deterministic approach sensitivity analysis involved varying of price elasticities, adoption levels and discount rates following Affognon (2010).

3.3.3 Probability weighted sensitivity analysis

The sensitivity analysis described above which follows a deterministic approach is a limited technique because it can handle only one or two variables in the analysis at a time while holding all the others constant. Probability weighted approach or risk analysis overcomes this limitation by allowing all the variables to vary at the same time. The cost-benefit analysis is best approached as a risk analysis because there is always some uncertainty in the data.

According to Alston *et al*. (1995), there are three approaches to dealing with risk and uncertainties in cost-benefit analysis. These are (i) expected values (certainty equivalents) of scenarios (ii) risk-adjusted discount rates, and (iii) risk analysis through simulation. The first two approaches have limited applicability. Only the third approach, simulation, offers a practical method for analysing the overall risk of a project.

Risk analysis or probability weighted sensitivity analysis can be carried out using Monte Carlo simulation of the NPV calculation (Alston *et al*., 1995). The idea is to attach a probability distribution to the variables entering the NPV calculation and then simulating a large number of draws from these distributions in order to find the resulting distribution of NPV (Alston *et al*., 1995). Knowledge of the probability distribution of the NPV makes it possible to assess the reliability of the cost-benefit analysis (Alston *et al*., 1995). The result of the simulation produces a cumulative distribution graph that shows how probable it is that the NPV will be lower or greater than a particular value (Alston *et al*., 1995).

3.4 Empirical model

3.4.1 Economic surplus model in a closed economy

To address the first objective, which was to measure the static *ex ante* economic returns to research on integrated thrips management in Loitokitok and Mwea sub – counties of Kenya, the economic surplus model was used. The basic model of research benefits in a closed economy is shown in Figure 3.4. Before adoption of IPM, Q_0 of tomatoes is demanded and supplied at price, P_0. Hence, the equilibrium is at (a) with P_0 and Q_0 on the equilibrium price and quantity. After the adoption and application of IPM in French beans and tomatoes, the supply curve of tomato production shift from S_0 to S_1, resulting in a new equilibrium price and quantity of P_1 and Q_1, respectively.

Gross research benefits are measured by the area beneath the demand curve and between the two supply curves, or the area I_0abI_1 in Figure 3.4. This area represents the total increase in economic welfare (change in total surplus), and comprises both the changes in producer and consumer surplus resulting from the shift in supply.

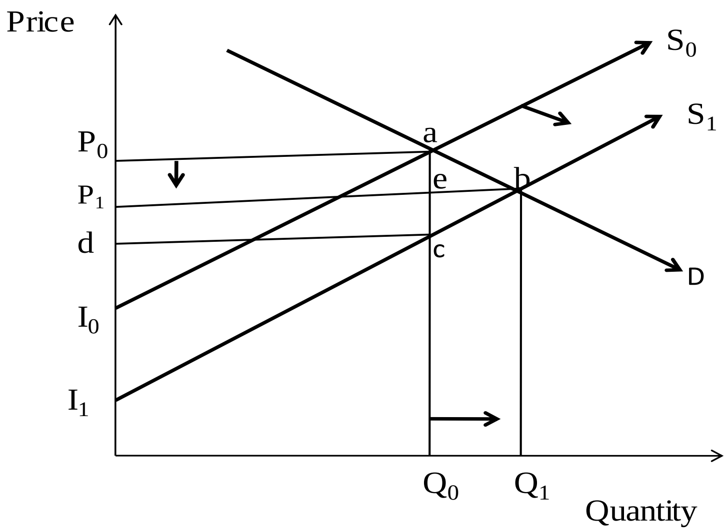

Figure 3. 4: Measuring change in total surplus

Source: Adopted from Alston *et al*. (1995)

where

D = Demand function for tomato

S_0= Supply function for tomato before research-induced change

S_1 = Supply function for tomato after research-induced change

P_0= Initial equilibrium price

P_1 = Price after research-induced change

Q_0 = Initial equilibrium quantity

Q_1 = Quantity after research-induced change

P_0abP_1 = Change in consumer surplus

P_1bcd = Change in producer surplus

I_0abI_1 = Change in total surplus (P_0abP_1 + P_1bcd)

Producer surplus (PS) is the return to quasi-fixed factors of production from selling a good at the equilibrium price, while consumer surplus (CS) reflects consumer's willingness to pay more for a good than the market price (Marshall, 1980). The size of PS and CS depend on the elasticity of supply and demand (Mishan, 1981). The algebraic derivation of the surpluses is shown in Table 3.1. Table 3.1 shows variables that were used in measuring potential benefits from use of integrated thrips management technology in tomato production in Loitokitok and Mwea sub-counties of Kenya.

Table 3.1: Variables used in measuring potential benefits from use of integrated thrips management technology in tomato production in Loitokitok and Mwea sub-counties of Kenya

Parameters	Formula	Value	Source
Elasticity of supply	$\varepsilon = \partial Q_s/Q_s/\partial P_s/P_s$	1.2	Giblin and Mathews
Elasticity of demand	$\eta = \lvert \partial Q_d/Q_d/\partial P_d/P_d \rvert$	0.79	Bundi *et al*. (2010)
		0.52	Ecker and Qaim (2008)
Proportionate increase in production (%)	$E(Y) = (Y_1 - Y_0)/Y_0$	0.2	Conservative
Cost change (%)	$C = E(Y)/\varepsilon$	0.2	Own calculation
Input cost change (%)	$E(C)$	-0.5	Appendix 3
Net reduction in cost (%)	$K = C - E(C)$	0.74	Own calculation
Relative reduction in price (%)	$Z = K\,\varepsilon / (\varepsilon + \eta)$	0.4625	Own calculation
Initial equilibrium price (USD)	P_0	343	HCDA (2012)
Quantity (before research induced change) (Tons)	Y_0	25	HCDA (2012)
Change in consumer surplus USD/Ha	$Z\, P_0\, Y_0\, [1 + (0.5Z\eta)]$		Own calculation
Change in producer surplus USD/Ha	$(K-Z)\, P_0\, Y_0\, [1 + (0.5Z\eta)]$		Own calculation
Change in total surplus USD/Ha)	$K\, P_0\, Y_0\, [1 + (0.5Z\eta)]$		Own calculation

Source: Adopted from Kristjanson and Zerbini (1999) and Alston *et al*. (1995)

where

K is the vertical shift of the supply function expressed as a proportion of the initial price

η is the absolute value of the elasticity of demand ε is the elasticity of supply

$Z = K\varepsilon / (\varepsilon + \eta)$ is the reduction in price relative to its initial pre-research value, due to the supply shift

P_s = Price at quantity supplied

P_d = Price at quantity demanded

Q_s = Quantity supplied

Q_d = Quantity demanded

P_0, P_1, Q_0 and Q_1 are as previously defined

3.4.2 Economic surplus model in an open economy

Because French beans constitute nearly 20% by volume and 10% by value of all fresh horticultural exports in Kenya (HCDA, 2008), a small open economy model was assumed. Figure 3.5 illustrates the changes in economic surplus from the adoption of IPM in French beans production.

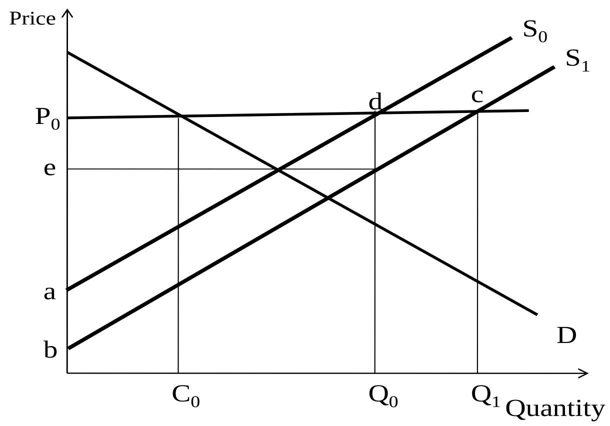

Figure 3. 5: Changes in economic surplus from IPM adoption in French bean production in a small exporting country

Source: Adapted from Alston *et al*. (1995)

The adoption of IPM shifts the supply curve downward from S_0 to S_1, and the domestic demand curve of French bean is assumed to remain unchanged. Given the open economy assumption, the price of French bean in Kenya is determined by the world market at P_0 and will not change because of the increasing supply in Kenya. Consumer surplus thus remains constant, whereas, producer surplus increases equal to the area *abcd*. In this case, Kenya could increase its exports to $Q_1 - Q_0$ (Alston *et al*., 1995).

The change in total surplus is equal to the change in producer surplus, since the consumer surplus remains constant as shown in equation 3.4.

$$\Delta PS = \Delta TS = P_0 Q_0 K\,(1 + 0.5K\,\varepsilon) \;\ldots\ldots\ldots\ldots\ldots\; (3.4)$$

where

ΔPS is the change in producer surplus

ΔTS is the change in total surplus

P_0 is the world price

ε is the supply elasticity

K is the proportional supply shift such that

$$K = \{[E(Y)] / \varepsilon - [E(C)] / [1 + E(Y)]\}\; pA\,(1-\delta) \ldots\ldots\ldots\; (3.5)$$

where

K is the proportionate downward shift in the supply curve due to IPM adoption in French bean production

$E(Y)$ is the expected proportionate yield change per hectare

$E(C)$ is the proportionate change in variable input costs per hectare to achieve the expected yield change

p is the success rate or the probability that IPM will achieve the expected yield

A is the adoption rate (proportional area of French bean under IPM to total French bean production area)

δ is the rate of annual depreciation of French bean under IPM (reduction of expected yield)

Table 3.2 shows variables that were used in measuring potential benefits from use of integrated thrips management technology in French bean production. Some of the values were obtained from experts including 3 Entomologists, 3 Plant pathologists and 3 Extension workers from Kenya Agricultural and Livestock Research Organization at National Agricultural Research Laboratories (KALRO NARL), Kenya Agricultural and Livestock Research Organization (KALRO) Thika and the Ministry of Agriculture, Livestock and Fisheries (MOALF) in 2014 using a questionnaire (Appendix 2). These experts were chosen based on their understanding of thrips and experience on research in integrated pest management.

Table 3. 2: Variables used in measuring potential benefits from use of integrated thrips management technology in French bean production in Loitokitok and Mwea sub-counties of Kenya

Variable	Value	Range	Source
Elasticity of supply	0.5	0.05 – 1	Kariuki *et al*. (2012)
Expected proportionate yield change per hectare (%)	0.25	0.1 – 0.4	Expert estimates
Proportionate change in variable input costs per hectare (%)	-0.2	-0.2	Author's own calculation. Cost of pesticides = US$ 793. IPM cost = US$ 636
Probability that IPM thrips will achieve expected yield (%)	0.5	0.2 – 0.69	Expert estimates
Proportional area of technology to total French bean production area in year t (%)	0.1	0.1	Author's own calculation
Rate of annual depreciation of the technology	4	4	Expert estimates
Proportionate downward shift in supply curve	0.46	1.98 – 0.36	Author's own calculation
World market price (US$/tonne)	1500	750 - 2250	HCDA (2012)
Quantity (before research induced change) (Tonne/Ha)	19	8.7 - 20	HCDA (2012)

Source: Various

3.4.3 Deterministic cost benefit analysis

For the base or 'most likely' scenario, the cost stream was taken as the annual project costs since inception in 2008. Research on IPM thrips ended in 2013. Table 3.3 shows values and range of variables obtained from a survey of experts for use in the deterministic cost-benefit analysis.

Table 3. 3: Values and range of variables obtained from a survey of experts for use in the deterministic cost-benefit analysis of research on integrated thrips management in French beans and tomatoes in Loitokitok and Mwea sub-counties of Kenya.

Variable	**Value**	**Range**
Adoption lag (years)	3	2 – 5
Adoption level (%)	54	30 – 80
IPM adoption (years)	7	4 – 10
Discount rate (%)	10	8 –12

Source: Expert opinion

A research lag of three years was assumed based on expert opinion (Table 3.3) and farmers would adopt the technology, on average, for seven years. During the research lag and all through the adoption period, the project would carry out extension activities at the rate of US$ 5 per farmer per annum. This cost was imputed from Perraton *et al*. (1983) who studied the cost of agricultural extension in Malawi.

Further, this study assumed that 10% of the French bean and tomato farmers would be reached by extension workers annually, for ten years, following Affognon (2010). Therefore, the cost of extension would be US$ 54,643 per annum. The adoption rate of the technology was expected to be 54%. In this study, a conservative technology adoption rate of 1% was assumed for the period 2017 to 2023 following Affognon (2010). Within this period, the cost of adoption was added to the cost of extension.

Benefits were assumed to accrue to farmers from 2017 following a three year lag. The changes in total surplus of both French beans and tomato were adjusted by 1,429 tomatoes and 9,500 French bean farmers (based on the total area under each crop and the average farm size of the sampled farmers) assumed to benefit from the knowledge and information generated from the project in the study area. These adjusted but uncertain benefits were then discounted at 10% per annum and compared against discounted research costs. Accordingly, investment methods of NPV, IRR and BCR were used to assess the potential impact of the IPM research for thrips control.

According to TBCS (1998) and Affognon (2010), a credible and more useful range for the social discount rate is normally about 8-12% per annum, with a most likely value of 10% per year. The cost of capital for agricultural loans was sought from Agricultural Finance Corporation (AFC) in 2014 and was 10%. This was consistent with subsidized lending rates for purchase of farm inputs at Equity Bank in Kenya at 10% during the time of the study.

3.4.4 Monte Carlo simulation of the Net Present Value

Monte Carlo simulation or probability simulation is a computerized mathematical technique that allows the incorporation of risk in quantitative analysis for decision making (Alston *et al*., 1995). The simulation furnishes the decision-maker with a range of possible outcomes and the probabilities they will occur for any choice of action (Alston *et al*., 1995). Monte Carlo simulation performs risk analysis by building models of possible results using a range of values—a probability distribution—for any input factor (Table 3.4) that has inherent uncertainty (Alston *et al*., 1995). It then calculates investment measures repeatedly, each time using a different set of random values from the probability distributions to produce distributions of possible outcome values (TBCS, 1998). Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands or tens of thousands of recalculations before it is complete (Alston *et al*., 1995).

In past literature, the pert, normal and triangular distributions are the most commonly used in risk models (Dillen, 2010). In this study, probability distributions that were computed for all the uncertain variables were based on the three methods – triangular, pert and normal (Table 3.4).

The normal distribution is represented as a bell-shaped curve. This distribution is completely described by two parameters– the mean and the standard deviation (Campbell and Brown 2003). Its range is the full extent of the real line, that is, from minus infinity to plus infinity, implying that, in principle, anything is possible, but only events in the vicinity of the mean are likely (ibid.).

The degree of dispersion of the possible values around the mean is measured by the variance or the square root of the variance – the standard deviation (s). When the standard deviation is divided by the mean we get the coefficient of variation which is a useful measure for comparing the degree of dispersion for different variables when their means differ. The degree of dispersion is a useful measure of the amount of risk. A high standard deviation implies a reasonable probability of the outcome being significantly higher or lower than the mean value, whereas a low standard deviation implies a relatively small range of likely outcomes in the vicinity of the mean (Campbell and Brown 2003).

Quite often, the analyst finds that there may be no reliable historical information about the variable in question and that he has no information beyond the range of values the variable could reasonably be expected to take. Here the analyst may still undertake a more formal risk modeling exercise than a sensitivity analysis by assuming a triangular or “three-point” distribution, where the distribution is described by a high (H), low (L) and best-guess (B) estimate, which provide the maximum, minimum and modal values of the distribution respectively. Each event in the range between L and H is assigned some probability, with values in the range of B being most likely. The precise specification and statistics for the three-point distribution can vary, depending on how much weight the analyst wishes to give to the mode in relation to the extreme point values. Clearly adopting a triangular distribution of this type is a “rough-and-ready” form of risk modeling and should only be used when insufficient information is available or resources prevent the obtaining of sufficient information to identify the characteristics of the uncertain variable's probability distribution more rigorously (Campbell and Brown 2003).

Although very popular, the triangular distribution might not be the best way to model expert opinions for modeling heterogeneity of technology valuation. Both tails are overemphasized and often experts have better knowledge on the central tendencies than on the extremes. Therefore the PERT distribution, a special case of the Beta distribution, is preferred for modeling expert opinions. It can range from highly skewed till symmetrical distributions, has a close fit to normal and lognormal distributions and attributes less weight to the extremes. The excessive reliance of the triangular probability distribution on the extremes also influences the variance introduced into the model (Dillen, 2010).

Table 3.4 Shows distribution of variables used in the Monte Carlo simulation of NPV of research on integrated thrips management in Loitokitok and Mwea sub –counties of Kenya.

Table 3. 4: Distribution of variables used in the Monte Carlo simulation of NPV of research on integrated thrips management in Loitokitok and Mwea sub –counties of Kenya.

Variables	Description	Value	Source
Q_{t1}	Tomato yield in low thrips incidence (Tons/Ha)	Triangular (23.9; 32; 48.7)	Ansah and Frimpong (2015)
Q_{t0}	Tomato yield in high thrips incidence (Tons/Ha)	Pert (21; 25; 31)	Affognon (2010)
Q_{b1}	French bean yield in low thrips incidence (Tons/Ha)	Triangular (9.9; 24.5; 31)	Ansah and Frimpong (2015)
Q_{b0}	French bean yield in high thrips incidence (Tons/Ha)	Pert (8.7; 19; 20)	Affognon (2010)
ε_t	Elasticity of supply of tomato	Pert (1; 1.1; 1.2)	Dillen (2010)
η_t	Elasticity of demand of tomato	Pert (0.52; 0.66; 0.79)	Dillen (2010)
ε_b	Elasticity of supply of French beans	Pert (0.05; 0.53; 1)	Dillen (2010)
P_{t0}	Price of tomato before intervention (US $/ton)	Pert (294; 343; 392)	Dillen (2010)
P_{b0}	Price of French beans before intervention (US $/ ton)	Pert (750; 1000; 1250)	Dillen (2010)
C_j	Investment cost during year j (US $)	Pert (2,320,802; 2,864,537; 3,408,272)	Affognon (2010)

I	Interest rate (%)	Triangular (0.08; 0.1; 0.12)	Ansah and Frimpong (2015)
Nbr_{tf}	Potential number of tomato farmers to be reached	Pert (1929; 3858; 7715)	Affognon (2010)
Nbr_{bf}	Potential number of French bean farmers to be reached	Pert (12825; 25650; 51300)	Affognon (2010)
YOR	Year one revenue (US $)	Triangular (2,756,510; 3,096,580; 4,037,780)	Own calculation
AFC	Annual fixed cost (US $)	Triangular (54,643; 137,498; 400,000)	Ansah and Frimpong (2015)
ARGR	Annual revenue growth rate (US $)	Normal (31%; 28%)	Own calculation
AVC	Annual variable cost as a %age of revenue (US $)	Normal (5%; 1%)	Own calculation

Source: Various

3.5 Data sources, assumptions and sampling procedures

3.5.1 Data sources and assumptions

Both primary and secondary data were used in this study. Primary data were collected through a semi-structured questionnaire (see Appendix 1) which was administered directly to farmers. The questionnaire captured farmers' bio - data (like age, gender, education level, income sources among others), farm characteristics (such as land size, major farm enterprises, distance to markets, access to extension service, type and number of livestock kept, asset ownership, input and output quantities and their respective prices, farming experience among others). The information captured by the questionnaire was also used to establish whether farmers knew about thrips and their rating of thrips as a constraint to farming. Lastly, thrips management practices and associated costs were also captured for both tomato and French beans.

(a) Market data

Secondary data were obtained from published literature and documents for government institutions such as Ministry of Agriculture, Livestock and Fisheries (MOALF) and HCDA. HCDA (2010, 2012) provided data on production and prices of French beans and tomato for 2006-2012 periods. Price elasticities of supply and demand were required to gauge whether the flow of benefits from adoption of IPM for thrips control would be realized as either a producer surplus or consumer surplus (Alston *et al*., 1995).

(b) Data from ICIPE's thrips IPM technology development and dissemination

Economic surplus and cost-benefit analyses of research require data and information related to production costs that change due to research. Accordingly, the cost of implementation of the technology by farmers was estimated from the cost of experiments set up at ICIPE and KALRO. These costs were provided by the project instructor (Dr. Subramanian, Personal

Communication). The annual cost of the project was obtained from the project's budget and work plan (Subramanian, 2011). It was assumed that the research activities would produce IPM package for thrips control in tomatoes and French beans. This technology would be disseminated among farmers in Loitokitok and Mwea sub- counties by extension workers from Loitokitok and Mwea sub- counties. Perraton *et al*. (1983) estimated the cost of agricultural extension service per farmer per annum in Malawi. The current study imputed Perraton *et al*.'s costs as the cost of extension service provided by staff from MOALF.

3.5.2 Samplingprocedure

There were no established sampling frames of farmers producing French bean and tomato in the two study sites. Accordingly, a geographic random sampling method was used to select farmers for the survey (Eng *et al*., 2007). Geographical random sampling was used to select a sample of 100 farmers in Loitokitok sub-*county* of Kajiado county and another 100 in Mwea sub-county of Kirinyaga county. To determine the sample size, the Cochran (1963) formula was used:

$$n = (Z^2pq)/ e^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

where:

n = Sample size

Z = Standard normal deviate at the selected confidence level; the value is 1.96 for commonly used 95% confidence interval

P = Proportion in the target population estimated to have characteristics being measured

q = 1 – p, which represents proportion in the target population estimated to be devoid of the characteristics being measured

e = the desired level of precision

In this case, p was determined as the proportion of farm families in Mwea East and Loitokitok sub–counties growing tomato and French beans. These were 508 and 1,265 farmers respectively (HCDA, 2012). The error term, e, was assumed to be 5 percent and corresponded to the desired confidence level.

$$n = 1.96^2 * 0.11 * 0.89/ (0.05)^2 = 150 \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.8)$$

Thus, the sample size was 300 respondents in total. According to Ortiz and Pradel (2010), samples of 60 to 100 farmers were found to be sufficient in estimating the impact of integrated pest management in any given crop enterprise.

Each survey site was defined as a circular area with an imaginative household at the centre of the circle as shown in Figure 3.6. The circular survey area was divided into grid cells, depending on population density so that, on average, each cell contained at least one household. Urban, unpopulated areas, forest and marshy areas were masked out. Finally, by applying a simple random sampling technique, 300 grids were randomly selected from all the grids in the circular survey area.

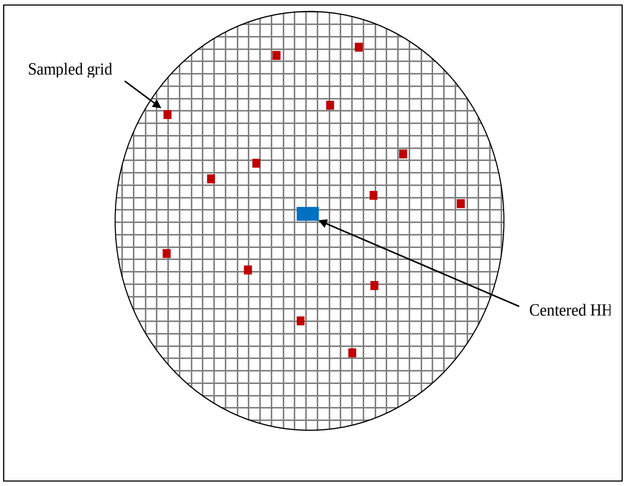

Figure 3. 6: Schematic representation of the geographic sampling frame used in sampling farmers in Loitokitok and Mwea sub – counties of Kenya.

Source: Adapted from Gelan and Muriithi (2010)

3.6 Study areas

The study areas were purposively selected because tomatoes and French beans are mainly produced in Kajiado and Kirinyaga counties (MOALF, 2013). According to HCDA (2012) the major tomato producing counties in Kenya are Kirinyaga and Kajiado counties with each producing 14% and 9% of total national production, respectively. This is because the crops are both rain-fed as well as irrigated whenever rain fails in these counties. Kirinyaga County (Figure 3.7) is located between latitudes $0^0$1` and $0^0$40` South and longitudes $37^0$and 38^0 East (Kariuki *et al*., 2006). It rises from about 1,158m in the South to 5,380m above sea level at the peak of Mt. Kenya. The county receives bi-modal rainfall with long rains occurring between March and May while the short rains fall between October and November (Kariuki *et al*., 2006). Given the physical features of the county, favourable climatic conditions and irrigation potential, agriculture is the mainstay and the main livelihood source of the people. The upper parts of the county produce mainly tea while rice is grown in paddies in the lower zones. Kirinyaga county leads in the production of French beans for export market in Kenya since late 1970s (Kariuki *et al*., 2006).

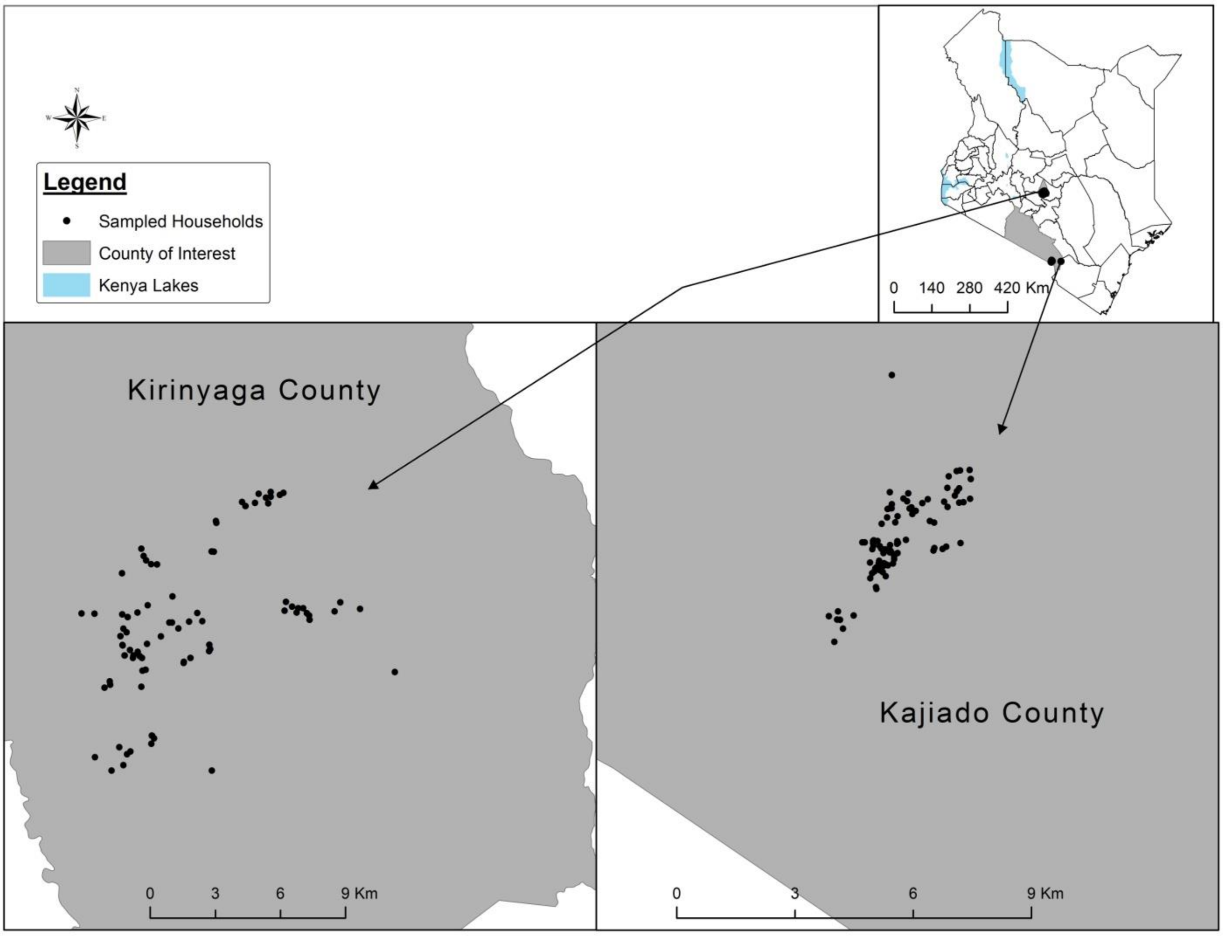

Figure 3. 7: Map of Kenya showing Kirinyaga and Kajiado counties

Source: Google Earth Software (2013)

Kajiado county lies between latitude 10 0` South and latitude 30 0` South of the equator and longitude 360 5` East and longitude 370 5` East (GOK, 2013). The short rains fall between October and December while long rains fall between March and May (GOK, 2013). Most parts of the county are arid and semi-arid with livestock rearing being the predominant economic activity. French bean is mainly grown under irrigation (GOK, 2013). Horticulture is gaining popularity through irrigation schemes mainly in Isinya and Kajiado North sub-counties.

3.7 Data collection

Data were collected using a questionnaire that was pre-tested between 1st May and 8th May, 2013. Two enumerators were selected in each study area based on their experience in data collection and their understanding of the local dialects. The enumerators were trained for two days by the author. The process of identifying respondent households and approaching the interviewees for the survey involved the following procedure.

- Each of the 200 grids was assigned latitude and longitude coordinate which was then uploaded into a global positioning system (GPS).
- The enumerators, guided by a GPS, went to the location and filled in the questionnaire by interviewing a household situated in that particular grid.
- If the enumerators encountered more than one household in the grid cell and the coordinate, they randomly selected one of the households.
- If there were no households in the vicinity of the GPS coordinate, then the enumerators randomly selected a direction (north, south east or west) and walked to the homestead being guided by the GPS.

Eventually, 299 respondents comprising 161 tomato and 138 French bean farmers were interviewed.

3.8 Data Analysis

Data for the deterministic model were captured in EXCEL software and analyzed using STATA. An EXCEL spreadsheet approach was used due to its simplicity for use in analysis. While specific IPM impact studies could obtain potentially more precise results from comprehensive and dynamic models, overall, the spreadsheet approach offers a good estimate of economic surplus induced by IPM research (Debass, 2000). The economic surplus model and formula for calculation of NPV, IRR and BCR were specified in EXCEL and the spreadsheet showed how model results changed with changes in variables.

The dynamic model simulated in 2014 involved setting up the basic model to calculate the NPV in @Risk software. This model was deterministic because it used a single stationary value for each variable over time (Affognon, 2010). The NPV was specified as follows:

$$NPV = \sum_{t=1}^{T} \frac{R_t - C_t}{(1+i)^t} \qquad \text{..............................(3.6)}$$

where

R_t = Benefit of research on IPM thrips in year t

C_t = Cost of investing in IPM thrips in year t

i = Discount rate

Probability distributions were assigned for all the uncertain variables as shown in Table 3.2. Finally, the number of iterations was specified. The number of iterations indicated how many random scenarios were to be generated. The more the iterations specified, the more accurate the results are assumed to be (Alston *et al*., 1995). In this study, 10,000 iterations were specified following Affognon (2010). The result of the simulation produced a list of NPVs, one for each iteration of the cost-benefit model. A cumulative distribution graph was then plotted to show how probable it was that the NPV would be lower or greater than a particular set value.

Sensitivity analysis involved varying elasticities, adoption and discount rates. Assumptions about the adoption levels started with a conservative level of 1%. The level was then increased to 2%, 5% and to 10% to examine the impact on predicted returns on investment on IPM thrips research based on the ceiling adoption level of 10% in EXCEL. Discount rates were varied by comparing the 10% project discount to lower and higher discount rates of 8%

and 12%. Variation of these parameters in EXCEL changed the results and these were captured in the spreadsheet.

CHAPTER 4: RESULTS AND DISCUSSION

This chapter presents the results obtained from the economic surplus analysis of IPM thrips in four parts. Part one presents the economic surpluses for tomatoes and French beans. Part two presents the base scenario deterministic cost-benefit analysis. Part three presents results of sensitivity analysis for the deterministic model. Part four presents the probability weighted sensitivity analysis.

4.1 Economic surplus for tomatoes

Table 4.1 presents the potential benefits from use of integrated thrips management technology in tomato production in Loitokitok and Mwea sub-counties of Kenya using the economic surplus model. As shown, IPM thrips had the potential to increase tomato production by 20% and reduce input cost by 50% on average. It also had the potential to reduce tomato prices by 46%. This means integrated pest management has potential to benefit both producers and consumers. Producers are expected to gain through reduced cost of production and economies of scale. On the other hand, consumers are expected to gain from the lower prices of tomatoes.

Bonabana-Wabbi *et al*. (2009) assessed the impact of tomato IPM packages on tomato production in Uganda. They found a 75% reduction in input cost attributed to the adoption of IPM, which was overly optimistic. The current study found a lower value of 20%. This could be attributed to the fact that the current study was *ex ante* while Bonabana-Wabbi *et al*.'s was *ex post*. The former employed conservative estimates of adoption rates, which could have led to the lower observed outcome. Gajanana *et al*. (2006) assessed the economic impact of adoption of IPM in tomato in India. The authors employed partial budgeting technique and found that the IPM technology was viable as the yield on IPM farms was higher by about 46 %, cost of cultivation reduced by about 21 % and the net returns were higher by 119 %.

Table 4. 1: Potential benefits from use of integrated thrips management technology in tomato production in Loitokitok and Mwea sub-counties of Kenya

Parameters	Minimum	Average	Maximum
Elasticity of supply	1	1.1	1.2
Elasticity of demand	0.52	0.66	0.79
Proportionate increase in production (%)	0.1	0.2	0.3
Cost change (%)	0.1	0.2	0.25
Input cost change (%)	-0.5	-0.5	-0.5
Net reduction in cost (%)	0.64	0.74	0.79
Relative reduction in price (%)	0.42	0.46	0.476
Price (USD)	294	343	392
Quantity (before research induced change) (Tons)	21	25	31
Change in consumer surplus (USD/Ha)	2,884.16	4,571.24	6,878.32
Change in producer surplus (USD/Ha)	1,499.77	2,742.74	4,528.22
Change in total surplus (USD/Ha)	4,383.93	7,313.98	11,406.54

Source: Own calculation

N/B: 1 USD = Kshs85 at the time of the study

The consumer welfare gain as measured by the consumer surplus was positive and higher than the producers' (Table 4.1). This was attributed to the expected reduction in the price of tomato following the 20% increase in tomato production and therefore supply. Further, the inelastic demand for tomato increased the consumer surplus as expected. These findings are consistent with those of Hristovska (2009) who in his study of IPM on tomatoes in Albania found that the change in consumer surplus and producer surplus were US$ 41, 882 and US$ 20,941 respectively. The surpluses though positive, were much higher and attributable to the fact that the study was *ex post* and the price of tomatoes per ton was lower and estimated at

US$ 308. In the current study the price of tomatoes was estimated at US$ 343. The low price of tomatoes in Albania could be explained by the higher proportionate increase in production, which was estimated at 50%, following a higher cost change of 50%. In the current study, a conservative proportionate increase in production and cost change of 0.2% and 0.2% respectively, was assumed.

The mean change in total surplus was positive US$ 7,313.98 (range = US$ 4,383 - US$ 11,406 per hectare) (Table 4.1). This means there is a huge potential benefit of adoption of IPM in thrips management on tomatoes, even at a conservative 1% adoption rate. Of the total surplus gain, 62.5% and 37.5% accrued to consumers and producers respectively, implying that the former were unambiguously better off than the latter. This is attributable to the higher utility derived by consumers from price reduction.

The fact that the two groups have a positive surplus gain suggests that the adoption of IPM technology for thrips management in tomatoes would lead to Pareto efficient outcomes, i.e., it does not leave one group better off while making the other worse off. These findings are consistent with those of Hristovska (2009) who found that the change in total surplus was positive and ranged from US$ 6,646 to US$ 11, 255 per hectare for adoption of IPM technology for various pests including thrips on tomatoes in Uganda. The slightly higher minimum reported in Hristovska (2009) is attributable to the higher expected yield that was pegged at 0.5%. The current study assumed a more conservative yield of 0.2%.

Further, the tomato IPM in Albania studied by Hristovska (2009) resulted in positive change in total surplus that ranged from US$ 41, 647 to US$ 62, 823 per hectare for adoption of IPM technology on various pests including thrips. These much higher results can be attributed to the *ex post* nature of the study. In addition, the IPM targeted various pests that is explained by the much higher reduction in input cost that was estimated at 50% against the 20% assumed in the current study.

4.2 Economic surplus for French beans

Table 4.2 presents the potential benefits from use of integrated thrips management technology in French bean production in Loitokitok and Mwea sub-counties of Kenya using the economic surplus model. The change in total surplus was positive with a mean of US$ 14, 758 (range = US$ 13,585 - US$ 18,849). This means there is a huge potential benefit of adoption of IPM in thrips management on French beans, even at a conservative 1% adoption rate. The change in total surplus all accrued to producers because there was no change in consumer surplus following the open economy assumption in the case of French beans. Consumer surplus remained constant since the price was pegged at the world market price.

Under the small open economy, producers will benefit from yield improvement and unit cost reduction (Napasintuwong and Traxler, 2009). Although there was no price reduction, research in integrated thrips management is still pareto efficient because producers are expected to realize massive gains leaving no consumers worse off. The consumer surplus does not change but in essence, consumers may still benefit from improved quality, more stability and continuity of French bean supply (Napasintuwong and Traxler, 2009). In addition, if integrated thrips management is adopted in other major exporting countries, consumers will eventually benefit from a decrease in world market price.

Comparing the open and closed economy, consumers benefit only from improved quality and price reduction. However, producers benefit less under a closed economy because higher supply suppresses the domestic price and generate less revenue than if price was fixed at the world market. Even though the consumer surplus becomes larger, a smaller total production level results in a smaller total surplus in the closed economy model as compared to the small exporting model (Napasintuwong and Traxler, 2009).

Table 4. 2: Potential benefits from use of integrated thrips management technology in French bean production in Loitokitok and Mwea sub-counties of Kenya

Parameters	**Minimum**	**Average**	**Maximum**
Elasticity of supply	0.05	0.5	1
Expected proportionate yield change per hectare (%)	0.1	0.25	0.4
Proportionate change in variable input costs per hectare (%)	-0.2	-0.2	-0.2
Success rate or probability that IPM thrips will achieve expected yield (%)	0.2	0.5	0.69
Proportional area of technology to total French bean production area in year t (%)	0.1	0.1	0.1
Rate of annual depreciation of the technology in year t (%)	4	4	4
Proportionate downward shift in supply curve	1.9836	0.46	0.3556
World market price (US$/Ton)	750	1500	2250
Quantity (before research induced change)	8.7	19	20
Change in consumer surplus (USD/Ha)	0	0	0
Change in producer surplus = Change in total surplus (USD/Ha)	13,585.09	14,757.98	18,849.77

Source: Own calculation

N/B: 1 USD = KShs85 at the time of the study

These findings are consistent with those of Napasintuwong and Traxler (2009) who estimated the *ex ante* impact assessment of genetically modified papaya adoption in Thailand using the economic surplus model and assumed a small open economy. The authors found that there was no change in consumer surplus. The change in total surplus which was equal to the change in producer surplus was estimated at US$ 386 million. These extremely high results could be attributed to the optimistic adoption level of 80% and an expected yield improvement of 495% that were assumed, in the study. This was explained by the lack of pesticide or herbicide use in the country that led to the no cost savings assumption. The current study assumed a conservative adoption rate of 1%, an expected yield improvement of 25% and a 20% reduction in input cost.

Further, Bayer *et al*. (2010) estimated *ex ante* the impact of papaya ring – spot virus (PRSV) resistant papaya in the Philippines, using the economic surplus model and assumed a small open economy. The authors found that there was no change in consumer surplus. The change in total surplus which was equal to the change in producer surplus was estimated at US$ 171 million. These results were much lower than those of Napasintuwong and Traxler (2009). This was attributed to the fact that the former study assumed a lower adoption lag of three years, a higher expected yield improvement of 495%, a lower price of US$ 161 and no cost reduction. The latter study assumed a higher adoption lag of seven years, a lower expected yield improvement of 77%, a higher price of US$ 363 and a cost reduction of 8%.

4.3 Deterministic cost benefit analysis

Table 4.3 shows results of cost-benefit analysis for use of integrated thrips management in Loitokitok and Mwea Sub-counties of Kenya. The NPV of the research regarding the assumptions made for the calculation was $ 4.8 million, with an IRR of 31% and a BCR of 4:1. These results indicate a positive NPV implying that the proposed integrated thrips management technology has fairly attractive returns even with the cautious assumption made about the adoption rate of 1%. The estimated IRR was higher than the market rate of 10% implying that investing capital in the IPM thrips management technology has potential of yielding a higher return than investing the same capital on alternative investments.

Most longer-run, low-risk, private-sector investments yield rates of return of around 8-10% (TBCS, 1998; Affognon, 2010) suggesting that investing in the integrated thrips management research would yield three times more return than alternative investments. A BCR of 4:1 means that the investor can expect US$ 4 in benefits for every US$ 1 in cost. This implies the technology is profitable and worth investing in.

These findings are similar to those of Hristovska (2009) who studied the economic impacts of IPM on tomatoes in Uganda. The study found NPV of US$ 1 million and an IRR of 169%. The study reported a lower NPV and a higher IRR and attributed this to lack of price data for tomatoes in Uganda, prompting the use of price data from neighboring countries. The current study estimated a higher NPV of US$ 4.8 million with an IRR of 31%. However this study estimated the potential economic impact of both tomatoes and French beans, with a small open economy assumption in the case of French beans, thereby using the world market price.

Evidence from the study conducted by Muthoka *et al*. (2010) on the economic impacts of IPM on tomatoes in Kenya showed a positive NPV of US$ 3.2 million and an IRR of 106%. The authors assumed an optimistic discount rate of 15%. The current study estimated a fairly higher NPV of US$ 4.8 million and an IRR of 31%. This is attributable to the conservative discount rate of 10%. Further, this study assessed the potential economic impact of integrated thrips management on both French beans and tomatoes.

Table 4.3 shows results of cost-benefit analysis for investing in research on integrated thrips management in tomatoes and French beans in Loitokitok and Mwea sub-counties of Kenya.

Table 4.3: Results of cost-benefit analysis for investing in research on integrated thrips management in tomatoes and French beans in Loitokitok and Mwea sub-counties of Kenya

Period	Costs	Benefits	Net Benefits	Discounted Costs	Discounted Benefits	Cumulated Discounted Benefits
2008	249993.1	0	-249,993	227,266	0	-227,266
2009	249993.1	0	-249,993	206,606	0	-433,872
2010	249993.1	0	-249,993	187,824	0	-621,696
2011	249993.1	0	-249,993	170,749	0	-792,444
2012	400000	0	-400,000	248,369	0	-1,040,813
2013	253570	0	-253,570	143,134	0	-1,183,947
2014	54643	0	-54,643	28,040	0	-1,211,987
2015	54643	0	-54,643	25,491	0	-1,237,479
2016	54643	0	-54,643	23,174	0	-1,260,653
2017	175473	3096580	2,921,107	67,652	1,193,866	-134,439
2018	175473	3096580	2,921,107	61,502	1,085,332	889,391
2019	175473	3096580	2,921,107	55,911	986,666	1,820,146
2020	175473	3096580	2,921,107	50,828	896,969	2,666,286
2021	175473	3096580	2,921,107	46,208	815,426	3,435,505
2022	175473	3096580	2,921,107	42,007	741,297	4,134,795
2023	175473	3096580	2,921,107	38,188	673,906	4,770,513
Sum of Discounted Costs = 1, 622, 949						
Sum of Discounted Benefits =6, 393, 462						
NPV = 4, 770, 513 IRR = 30.96 BCR = 4:1						

Source: Own calculation

Based on the results presented in Table 4.3, the null hypothesis that there was no potential economic return to research initiated by ICIPE on integrated thrips management in tomatoes and French beans in Loitokitok and Mwea sub-counties of Kenya could not be sustained. This is because all the investment appraisal indicators (i.e., the NPV, IRR and BCR) were positive with the IRR being greater than the opportunity cost of capital. This implies that integrated thrips management technology has potential to yield returns that are greater than the cost of capital and hence, a profitable investment.

4.4 Sensitivity analysis for the deterministic approach

The analysis conducted above attempts to assess the potential economic impact of research investment assuming certainty in both the timing of costs and benefits as well as knowledge of the adoption profile of potential adopters. In the real world, this is not always the case. In order to account for uncertainty in the timing of costs and benefits and knowledge of adoption rates, a sensitivity analysis was undertaken on the results to test validity and robustness of the assumptions made in the economic surplus model. This involved changing both the adoption and discount rates.

4.4.1 Effect of changing adoption rates

Assumptions about the adoption levels started with a conservative level of 1%. The level was increased to 2%, 5% and to 10% to examine its impact on predicted returns on investment on IPM thrips research based on the ceiling adoption level of 10% following Affognon (2010). The results are presented in Table 4.4. Table 4.4 shows a summary of effect of changes in adoption rates on investment ratios for integrated thrips management in tomatoes and French beans in Loitokitok and Mwea sub-counties of Kenya.

Table 4.4: Summary of effect of changes in adoption rates on investment ratios for integrated thrips management in tomatoes and French beans in Loitokitok and Mwea sub-counties of Kenya

	Levels of adoption (% of farmers reached)	Net Present Value (NPV) ($)	Internal Rate of Return (IRR) (%)	Benefit Cost Ratio (BCR)
Scenario 1	1%	4,043,682	29.1	3:1
	2%	9,460,837	39.64	6:1
(absolute minimum elasticity)	5%	25,712,301	54.79	11:1
	10%	52,798,076	67.28	15:1
Scenario 2	1%	4,770,513	30.96	4:1
	2%	10,914,499	41.64	7:1
(absolute average elasticity)	5%	29,346,456	56.99	12:1
	10%	60,066,386	69.65	17:1
Scenario 3	1%	6,713,794	35.11	5:1
	2%	14,801,061	46.09	9:1
(absolute maximum elasticity)	5%	39,062,863	61.89	16:1
	10%	79,499,199	74.94	22:1

Source: Own calculation

Figure 4.1 shows changes in NPV, IRR and BCR with changes in adoption rates at absolute minimum elasticity.

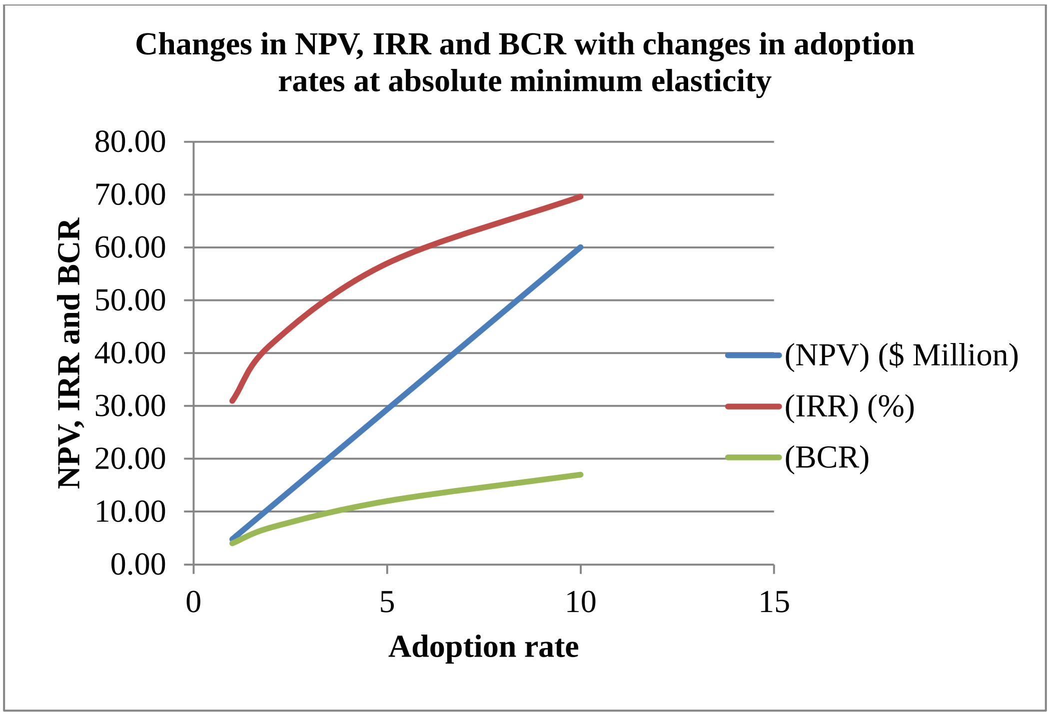

Figure 4. 1: Changes in NPV, IRR and BCR with changes in adoption rates at absolute minimum elasticity

Source: Author

In the first scenario where minimum absolute values of supply and demand elasticities were assumed, at 2% adoption, the BCR doubled, the NPV increased by 134% while the IRR increased by 36%. Assuming a 5% adoption rate, increased the NPV, IRR and BCR by 536%, 88% and 267% respectively (Figure 4.1).

Figure 4.2 shows changes in NPV, IRR AND BCR with changes in adoption rates at absolute average elasticity.

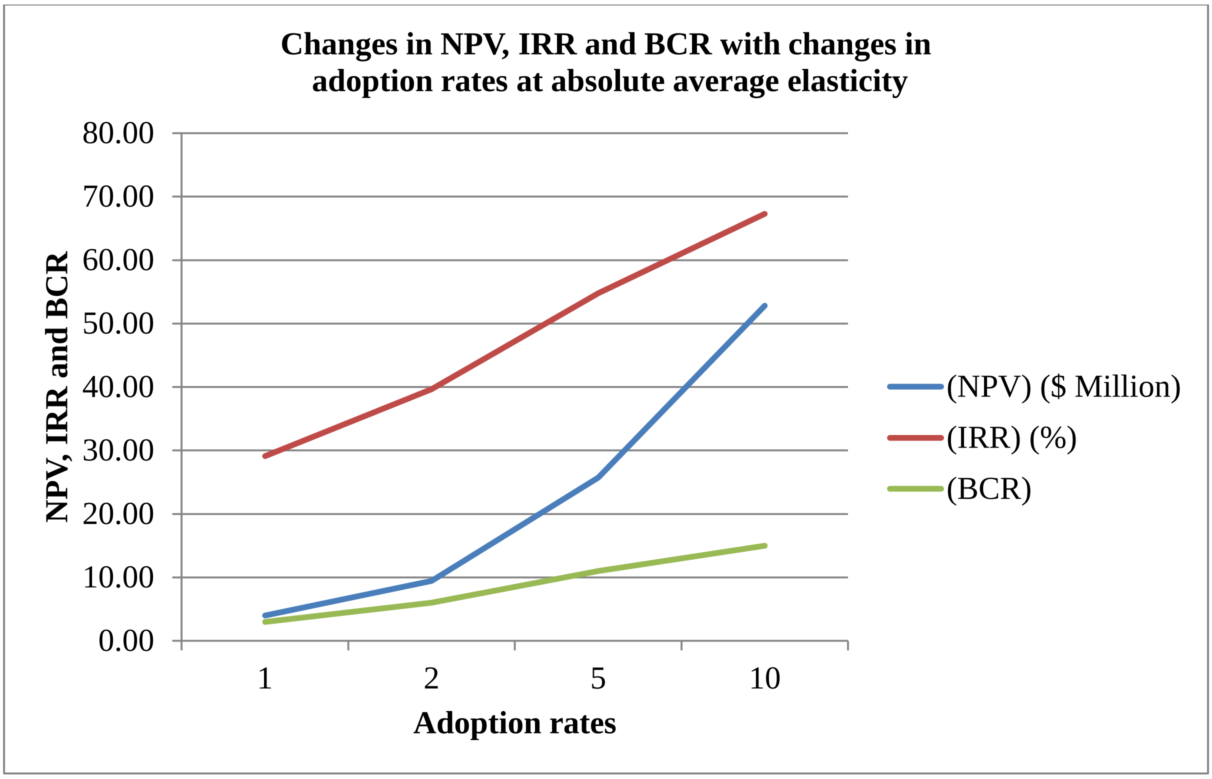

Figure 4. 2: Changes in NPV, IRR and BCR with changes in adoption rates at absolute average elasticity

Source: Author

In the second scenario where average absolute values of supply and demand elasticities were assumed, at 2% adoption rate, the NPV, IRR and BCR increased by 129%, 34% and 75% respectively. On the other hand, assuming a 5% adoption rate increased the NPV five-fold, IRR by 84% while the BCR tripled (Figure 4.2).

Figure 4.3 shows changes in NPV, IRR AND BCR with changes in adoption rates at absolute maximum elasticity.

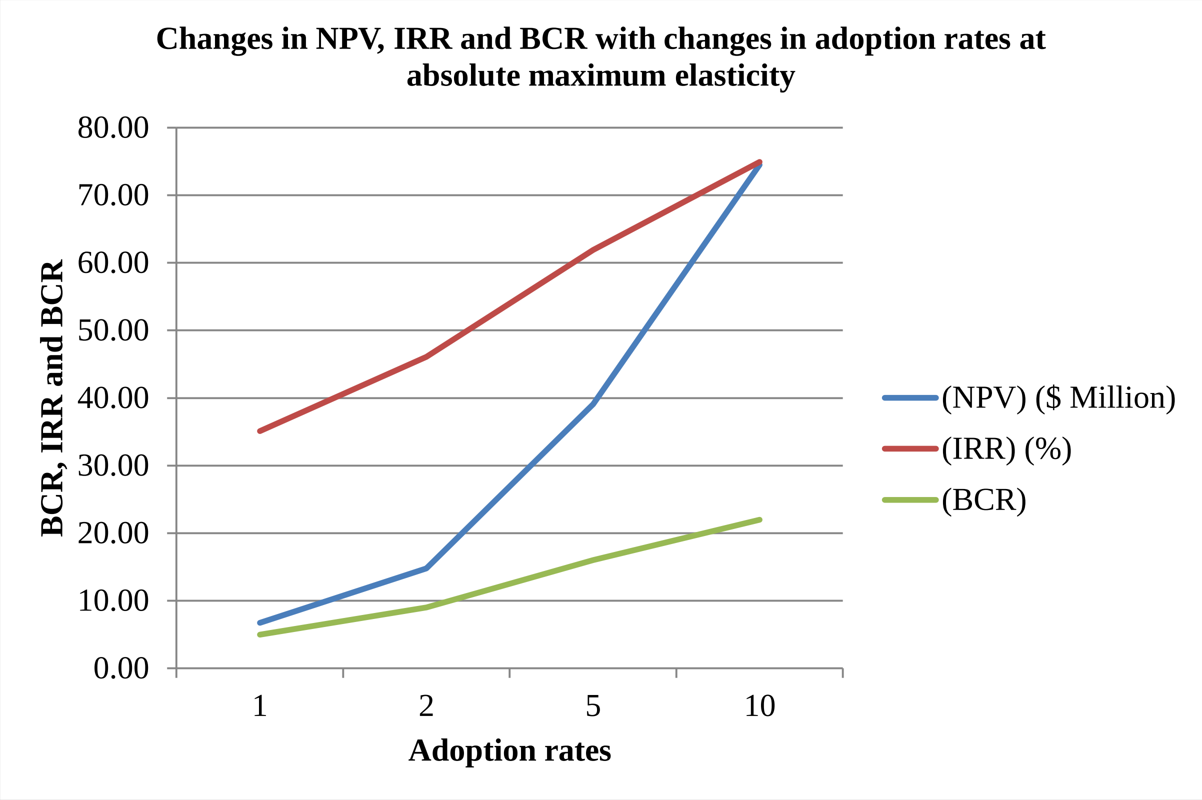

Figure 4. 3: Changes in NPV, IRR and BCR with changes in adoption rates at absolute maximum elasticity

Source: Author

In the third scenario where maximum absolute values of supply and demand elasticities were assumed, at 2% adoption rate, the NPV, IRR and BCR increased by 120%, 31% and 80% respectively. Assuming a 5% adoption rate raised the NPV by 482%, IRR by 76% and BCR more than tripled (Figure 4.3).

These results show that the predicted returns on investment were sensitive to changes in the adoption rates. Thus, the NPV, IRR and BCR increased at an increasing rate as adoption rates increased. This implies that the potential economic benefits of integrated thrips management highly depend on adoption decisions by the farmers. Therefore, ICIPE and the government through extension agents need to actively promote the technology to ensure high adoption levels by the farmers. These findings tally with that of Affognon (2010) who estimated the potential impact of BMZ investments in trypanocide resistance research in West Africa and found that at the absolute average elasticity and adoption rate of between 1% and 5% the NPV ranged between USD 30M and USD 159M. This range is higher than that of the current study of between USD 4M and USD 30M. This is attributed to the fact that the study by Affognon (2010) focused on animal products which are of a higher value.

4.4.2 Effect of changes in the discount rate

Table 4.5 shows the effect of changes in the discount rate on returns on investments by comparing the 10% project discount to lower and higher discount rates of 8% and 12% respectively. In the first scenario where minimum absolute values of supply and demand elasticities were assumed, at 12% discount rate, the NPV and the BCR fell to $3 million and 3:1 respectively. However, at 8% discount rate, the NPV and the BCR increased to more than $5 million and 4:1, respectively. In the second and third scenario, the same trend was observed for the NPV and BCR. The IRR was 29%, 31% and 35% respectively, in the first, second and third scenarios, respectively. There was no difference in IRR between different levels of the discount rate. These results indicate that, as expected, investment in IPM for thrips management in tomatoes and French beans in Loitokitok and Mwea sub-counties of Kenya is worthwhile at lower discount rates.

Table 4.5: Summary of effect of changes in the discount rate on investment ratios for integrated thrips management in tomatoes and French beans in Loitokitok and Mwea sub-counties of Kenya

Scenario	Levels of discount rate	Net Present Value (NPV) ($)	Internal Rate of Return (IRR) (%)	Benefit Cost Ratio (BCR)
Scenario 1	8%	5,342,338	29.1	4:1
(absolute minimum elasticity)	10%	4,043,682	29.1	3.5:1
	12%	3,046,778	29.1	3:1
Scenario 2	8%	6,259,193	30.96	4.5:1
(absolute average elasticity)	10%	4,770,513	30.96	4:1
	12%	3,626,127	30.96	3.5:1
Scenario 3	8%	8,710,531	35.11	5.8:1
(absolute maximum elasticity)	10%	6,713,794	35.11	5.1:1
	12%	5,175,094	35.11	4.5:1

Source: Own calculation

Lower discount rates imply cheaper cost of capital and hence higher returns reflected by investment appraisal indicators. While assessing the potential returns to international trypanosomosis vaccine research, Kristjanson *et al*. (1999) found that a 5% - 10% discount rate yielded NPVs of between USD 288 million and 103 million. This further reinforced the earlier assertion that projects seem worthwhile at lower discount rates. In the current study, an 8% - 10% discount rate yielded NPVs of between USD 6 – 4M. Consequently, there is need for the government to regulate interest rates to ensure affordable credit in order for research institutions such as ICIPE to upscale integrated pest management technologies.

4.5 Probability Weighted Sensitivity Analysis

The sensitivity analysis computed above follows a deterministic approach and it is a limited technique because it can handle only one or two variables in the analysis at a time while holding all the others constant. Probability weighted approach or risk analysis is necessary to be computed because it overcomes this limitation by allowing all the variables to vary at the same time. Figure 4.4 shows the cumulative probability distribution of NPV generated from the @Risk software for risk analysis. As shown in the Figure, the possible NPVs ranged from US$63.16 million to US$66.6 million, with a mean of US$64.96 million. This implies that the potential NPV of research on integrated thrips management is expected to fall in the positive region. Therefore, implementation of integrated thrips management in tomatoes and French beans in Loitokitok and Mwea sub-counties of Kenya would be of benefit to both the adopting farmer and the consumer. Further, the range of the possible NPVs indicates the possibility of the technology yielding higher returns than the cost of capital. This implies that the technology is worth investing in by ICIPE and the government through extension agents needs to actively promote the technology to ensure maximum adoption by the farmer.

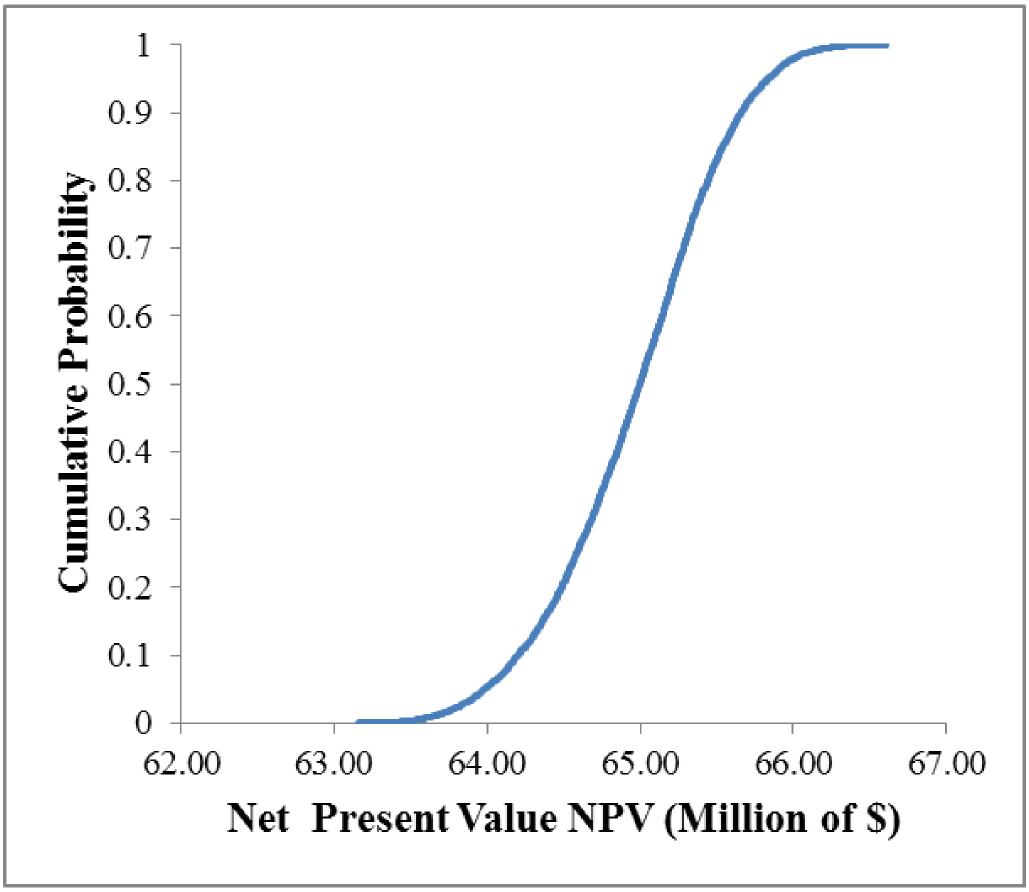

Figure 4. 4: Cumulative probability distribution of research on integrated thrips management in Loitokitok and Mwea sub –counties of Kenya

Source: Author

These findings are consistent with cumulative distributions of efficient research portfolios discussed by Gierend (1999) as shown in Figure 4.4. According to the author, efficient research portfolios display positive cumulative probability distributions of NPVs, indicating that the research in integrated thrips management is expected to be efficient.

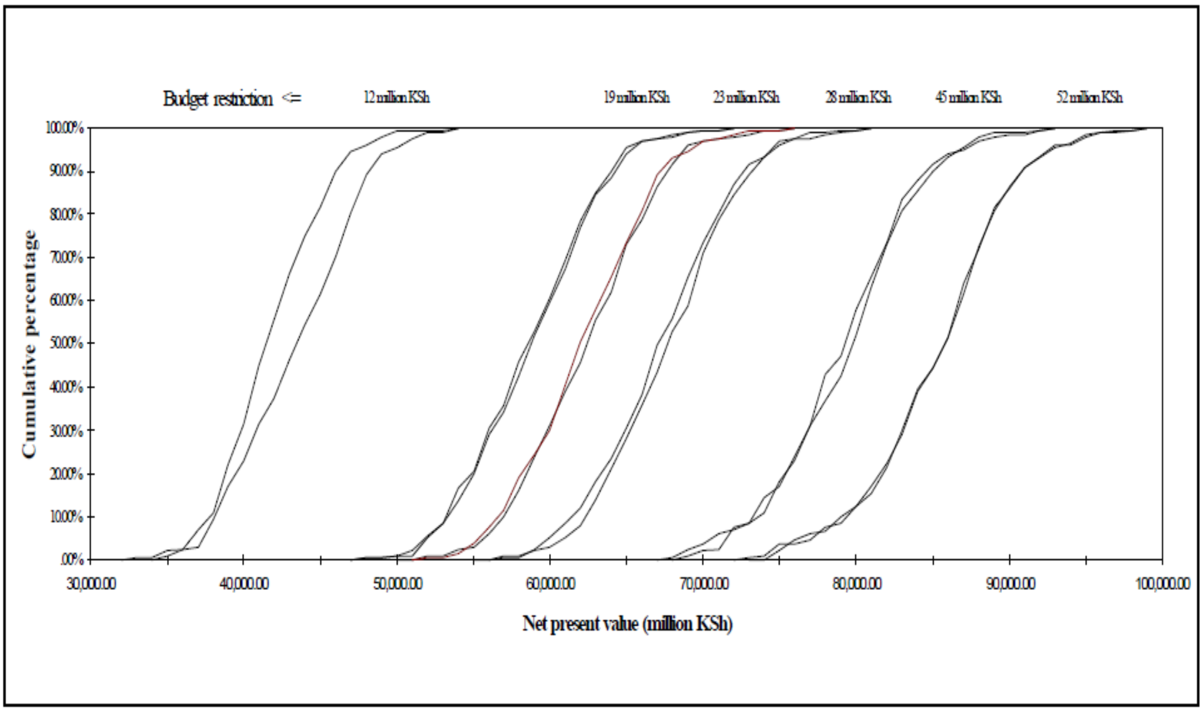

Figure 4. 5: Cumulative distributions of selected utility-efficient research portfolios

Source: Adapted from Gierend (1999)

Affognon (2010) estimated the potential impact of BMZ investments in trypanocide resistance research in West Africa and found the possible range of Net Present Values to range from about - €9264 millions to €36284 million. The probability that the NPV would be greater than zero was 75%. In the current study, the probability that the NPV would be greater than zero was 100%. This implies that the current study is less risky. This is attributable to the fact that the current study assumed an adoption lag of three years whereas Affognon (2010) assumed an adoption lag of 15 years.

4.6 Limitations of the study

Due to the nature of *ex ante* research assessment, the study depended heavily on secondary data and expert opinion. The *ex ante* parameters of technology generation and adoption were mostly based on the subjective opinion of scientists and researchers in KALRO NARL, KALRO Thika and MOALF. This would have introduced potential bias in the estimates due to scientists/researchers' vested interests about the outcome of this study. However, conservative estimates were used in this study. Additionally, there was little information on price elasticities of demand and supply of tomatoes and French beans in Loitokitok and Mwea sub-counties of Kenya. Estimates of supply and demand for tomatoes and French beans from other regions with a similar market structure to that in Loitokitok and Mwea sub-counties were used instead. Studies have shown that imputed estimates are often less accurate than actual values due to the bias in the standard errors of parameter estimates (Dong and Peng, 2013). However, in this study, risk analysis was carried out on NPV in a Monte Carlo simulation in order to analyze the robustness and model sensitivity to the underlying parameter estimates and assumptions.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

In Kenya, thrips cause nearly 60-80% and up to 80% yield losses in French bean and tomato respectively. Farmers rely extensively on insecticides to manage the thrips. This despite insecticides having been shown to possess minimal efficacy due to high levels of resistance by thrips, environmental risks, increased production costs and limited export due to non-compliance to maximum residue levels in export countries. The ICIPE and its partners are proposing the use of integrated pest management (IPM) for the control of thrips in French beans, tomato and onions in Loitokitok and Mwea sub-counties of Kenya. However, before the dissemination of the developed technologies, there is need to assess the potential economic impact of the use of IPM technology in the control of thrips in French beans and tomato in Kenya. Such information is currently missing specifically as pertains to Loitokitok and Mwea sub-counties of Kenya. Lack of such information leads to uncertainty in as far as investment in research and technology promotion is concerned. The specific objectives of this study were to (i) measure the static *ex ante* economic returns to research on integrated thrips management in Kenya, and (ii) measure the dynamic *ex ante* economic returns to research on integrated thrips management in Kenya.

To achieve these objectives, geographical random sampling was used to select a sample of 150 farmers in Loitokitok sub-county and 150 farmers in Mwea sub-county of Kajiado and Kirinyaga counties respectively. The economic surplus model was employed to measure the potential benefits of thrips IPM research. The benefit: cost ratio (BCR), the Net Present Value (NPV) and the Internal Rate of Return (IRR) were calculated using the Cost-Benefit Analysis (CBA) framework. Sensitivity analyses were undertaken to assess the effect of changes in discount and adoption rates on the investment ratios. In addition, risk analysis was undertaken to test validity of NPV using Monte Carlo simulation. The result of the simulation produced a list of NPVs with the probabilities of their occurrence to assess the risk associated with implementing the technology.

The study found that investment in IPM thrips control would give substantial benefits discounted over 16 years to both consumers and producers. Assuming a conservative adoption rate of 1% and a 10% discount rate for the base deterministic scenario, the NPV of the research was estimated at $ 4.8 million, with an IRR of 31% and a BCR of 4:1. These results imply that investment in integrated thrips management in Kenya has potential benefits that outweigh the cost of capital and hence worth investing in. The potential benefits are expected to accrue to both farmers and consumers hence promotion and eventual adoption of the technology by farmers is justified.

The results of the sensitivity analysis for the deterministic approach estimated the range of NPV at $4 - $79 million, IRR (29% - 75%), and the BCR, (3:1 – 22:1), assuming a conservative adoption rate of 1% to 10% and a 10% discount rate. These results mean that potential benefits of integrated thrips management are expected to increase with adoption levels at a given discount rate. It is thus incumbent upon the government to ensure promotion of the technology through extension agents and stabilize interest rates to ensure higher benefits of research on IPM thrips. The Monte Carlo simulation undertaken at 10% discount rate found a range of possible NPVs from $63.16 million to $66.6 million. This means that NPV is expected to fall in the positive region, indicating that investing in the thrips IPM technology is financially worth considering.

5.2 Conclusions

The growing food insecurity, poverty and limited exports in developing countries provide potential opportunity to improve quality and quantity of food through development of integrated pest management. The potential economic impact of integrated thrips management in French beans and tomatoes in Loitokitok and Mwea sub-counties of Kenya was measured using the economic surplus model. The results of the study showed that the technology was Pareto-efficient as both consumers and producers recorded gains. The consumers were expected to benefit from reduced prices due to increased supply of more and healthier tomatoes and French beans. On the other hand, producers would benefit from reduced cost of production that would allow them to produce more and further benefit from economies of scale.

This study found that ICIPE's thrips IPM technology was both financially viable and would lead to Pareto-efficient welfare-maximizing outcomes for both consumers and producers. It is therefore worth pursuing.

5.3 Policy recommendations

A fundamental variable during the economic surplus modeling is that the impact of IPM thrips depends on successful adoption of the technology by the farmers. The following recommendations are suggested based on the findings:

1. Sensitivity analysis of adoption rates highlights the fact that gains from research are sensitive to adoption rates. Efforts to promote the adoption of IPM thrips technology are encouraged to ensure more efficient production and greater economic rewards for the farmer and the country as a whole.

2. The IPM strategy should be introduced into vegetable production practices in non-project areas through developmental planning of the vegetable sector.

3. This study found that the IPM thrips technology was worthwhile at low discount rates. Thus, the Government of Kenya should introduce interest rate control especially on agricultural credit to encourage investment and adoption of IPM thrips technology.

5.4 Areas of further research

This study attempted to measure the potential economic impact of IPM thrips in French beans and tomatoes in Kenya. However, IPM thrips has potential to spillover to other counties. Further, IPM has positive environmental impacts that can be measured through the air, water and soil quality after implementation of IPM. The health of non-target species of mammals, birds, fish, insects, plants and other life forms is also bound to improve as a result of shunning harmful pesticide use. Human health impacts could also be measured since IPM minimizes use of pesticides and pesticide exposure. If measured, all these other potential benefits could increase the potential benefits of IPM thrips. Therefore, a study on the potential environmental and human health impact of integrated thrips management is urgently needed.

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APPENDICES

APPENDIX 1: FARMERS' QUESTIONNAIRE

POTENTIAL ECONOMIC IMPACT OF INTEGRATED THRIPS MANAGEMENT IN FRENCH BEANS AND TOMATO IN KENYA

INTRODUCTION TO THE RESPONDENT

Hello, my name is ……………..……and I am part of the research team assisting in an on-going research by Esther Achieng' Mujuka in partial fulfillment of her MSc. degree at the University of Nairobi. We are conducting a baseline survey to establish the current status of vegetable production influenced by the thrips constraints. This is part of a study to evaluate the potential economic impact of an integrated Pest Management (IPM) technology that the International Centre of Insect Physiology and Ecology (ICIPE), has developed to deal with thrips (pests) in French beans and tomato in Kenya. Note that the information offered herein shall be confidential and crucial in comparing the scenario without the technology and the scenario after implementation of the technology. The result will determine the perception on the effectiveness of the technology, need for dissemination and constraints to adoption. Therefore, kindly offer honest responses.

Name of Enumerator:.......................................Date:..

Coordinates: .... .District:..

Sub-Location:...................................…..........Village: ....

Time Start: ....Time End: ....

Section A. Personal Details

1. Respondent's name ………………………………………………

2. Household head name (If different)………………………………………

3. Gender of household head 1 = Male □ 0 = Female □ (Tick where applicable)

4. What is the age of the household head?....................... (in years)

5. What is the highest level of education of the household head**?**

   0= None □ 1= Incomplete primary school □

   2= Completed primary school □ 3= Incomplete secondary school □

   4= Completed secondary school □ 5= Village polytechnic □

   6= Tertiary college □ 7= University □

6. How many years did the household head spend in school? …………….(in years)

7. What is the number of household members?............................

8. Please fill the following table on household composition:

Age	Male	Female	Total
0 year to 14 years			
15 years to 64 years			
More than 64 years			

9. How many children go to school? …………

10. Please rank sources of family's income based on their importance.

	Sources of family's income	Rank
1	Farming including livestock keeping	
2	Employment	
3	Business	
4	Others (Specify)	

11. In the case of farming, including livestock keeping as a source of income, how many of the family members are actively engaged in farming?.....................

12. What is the cost of hired labour?..

Section B: Socio-economic factors

1.What is the size of your farm in acres? ....

	Ownership	Quantity (acres)
1.	Land owned	
2.	Rented land	
3.	Communal land	
4.	Other (Specify)	

2. How many market centers are within your reach?....................

3. How far is your farm from the nearest market center in?

1 = Kms?...................... 2 = Walking hours……..

4. Have you ever received agricultural extension services? 1 = Yes □ 0 = No □

5. If yes, who provided the services? 1 = Ministry of Agriculture □ 2 = NGO (Specify) □

………………………………………

6. Which subjects were covered by the extension service provider?

1 = Safe use and handling of pesticides □

2 = Farming as a business □

3 = Good agronomical practices □

4 = Crop protection □

5=Others (specify)…………………………

7. Do you own livestock? 1 = Yes □ 0 = No□

8. If Yes, how many of each type? (please fill the table)

Livestock type	**Total number**	**Livestock type**	**Total number**
Cattle adult		Donkey	
Goat		Camel	
Sheep		Poultry	

9. Other assets owned

Other assets	Total number	Other assets	Total number
TV		Fridge	
Radio		Gas Cooker	
Bike		Microwave	
Motorbike		Video	
Car		Computer	
Mobile phone		Internet connection (modems)	
Fix telephone at home			

Section C. Farming Data

1. Which horticultural crops did you cultivate in the last season?

Enterprise	Variety	Acreage	Cost of land preparation	Total Production (Kg)
French bean				
Tomato				
Onions				
Others				

2. For the acreage and level of production indicated above, please indicate the costs incurred on the table below.

Enterprise	Costs (Kshs)								
	Seed	Basal fertilizer	Top dressing fertilizer	Cost of labour					
				Planting	Top dressing	Weeding	Harvesting	Water	Total labour
French bean									
Tomato									
Onions									

3. For how many years have you been cultivating horticultural crops?.........................

Section D: Produce Marketing

1. Did you sell any produce last season? 1 = Yes □ 0 = No □

2.If yes, specify what produce, quantity consumed, quantity sold, price per unit and total income in the table below.

No.	Produce	Quantity consumed (Kg)	Quantity sold (Kg)	Price per Kg (Ksh)	Total income from sale (Ksh)	Marketing channel*
1.						
2.						
3.						
4.						

***Marketing channel: 1= sold at farm gate, 2=sold at local market 3=sold to middlemen 4=Exported**

N/B: Whether or not you sold your produce, fill column 5 above on price for French bean, tomato and onions.

3. If no in 1 above, why did you not sell any produce?

1 = No surplus □ 2 = Low market prices □ 3 = Poor produce quality □

4 = Distance to market □ 5 = Others (specify)……………………………………

Section E: French Bean Production Practices

1. Are there any constraints that you encounter in the production of French beans?

1 = Yes □ 0 = No □

2. If yes, which are some of the major constraints?

1). Insect attacks 2). Occurrence of diseases

3). High cost of certified seed and fertilizer 4). Others (specify)……

3. Using the following pictures, please show symptoms of thrips presence in French beans.

(Tick where appropriate.)




□ 1 □ 2 □ 3□ 4

4. How would you rate thrips as a constraint on your farm?

1= Not a pest 2= Minor pest 3= Occasional pest 4= Major pest

5. If thrips are observed as a constraint, how do you manage them?

Pest Management practice	**1= Yes**	**0= No**	**Please give details**
Use of resistant varieties			
Intercropping			
Monitoring of thrips numbers			(e.g manual counting/ Coloured sticky traps)
Spraying of plant based pesticides such as neem, Pyrethrum and others.			
Spraying of synthetic pesticides.			If yes, give details in question 6-8

Biological control			
Others			

6. If pesticides are used to control thrips or diseases caused by thrips (symptoms described above), how do you determine when to apply pesticides to your French beans?

1 = Whenever I see a pest □ 2 = Only after scouting for pests □

3 = Using spray calendar/program □ 4 = When advised by chemical trader□

5 =When advised by the buyer's staff □ 6 = When a neighbor sprays □

7 = When advised by other farmers □ 8 = Whenever I see a sign of disease □

9 = Other (specify)……………………

7. If pesticides are used, please fill the following table.

Date/ Stage of crop	Trade name of pesticide	Common name (active Ingredient)	Area treated	Frequency of application	Cost of labour (kshs)	Pesticide amount (kg/ltrs)	Pesticide costs (cost per unit of weight)
Planting to 3-leaf formation							
3-leaf to flowering							
Flowering to harvesting							
Start to end of harvesting							

8). If no laborers are hired to apply pesticides, how many household members are involved in the activity from planting to end of harvesting? ....

9). Are there any other pest management practices that attract costs? 1 = Yes □ 0 = No □

10). If yes in 9 above, please indicate them in the following table.

Practice	Type	Cost per unit (indicate the unit)
Use of resistant varieties		
Irrigation		
Biological control		
Intercropping		

11). What is the cost of non-resistant seed varieties?.................................

Section F: Tomato Production Practices

1. Are there any constraints that you encounter in the production of tomato?

   1 = Yes ◻ 0 = No ◻

2. If yes, which are some of the major constraints?

   1). Insect attacks 2). Occurrence of diseases

   3). High cost of certified seed and fertilizer 4). Others (specify)………………

3. Using the following pictures, please show symptoms of thrips presence in tomato.

   (Tick where appropriate.)

◻ 1 ◻ 2 ◻ 3◻ 4

4. How would you rate thrips as a constraint on your farm?

   1= Not a pest 2= Minor pest 3= Occasional pest 4= Major pest

5. If thrips are observed as a constraint, how do you manage them?

Pest Management practice	**1= Yes**	**0= No**	**Please give details**
Use of resistant varieties			
Intercropping			
Monitoring of thrips numbers			(e.g manual counting/ Coloured sticky traps)
Spraying of plant based pesticides such as neem, Pyrethrum and others.			
Spraying of synthetic pesticides.			If yes, give details in question 6-8
Biological control			
Others			

6. If pesticides are used to control thrips or diseases caused by thrips (symptoms described above), how do you determine when to apply pesticides to your tomato?

1 = Whenever I see a pest □ 2 = Only after scouting for pests □

3 = Using spray calendar/program □ 4 = When advised by chemical trader□

5 =When advised by the buyer's staff □ 6 = When a neighbor sprays □

7 = When advised by other farmers □ 8 = Whenever I see a sign of disease □

9 = Other (specify)……………………

7. If pesticides are used, please fill the following table.

Date/ Stage of crop	Trade name of pesticide	Common name (active Ingredient)	Area treated	Frequency of application	Cost of labour (kshs)	Pesticide amount (kg/ltrs)	Pesticide costs (cost per unit of weight)

8). If no laborers are hired to apply pesticides, how many household members are involved in the activity from planting to end of harvesting?..

9). Are there any other pest management practices that attract costs? 1 = Yes □ 0 = No □

10). If yes in 9 above, please indicate them in the following table.

Practice	Type	Cost per unit (indicate the unit)
Use of resistant varieties		
Irrigation		
Biological control		
Intercropping		

11). What is the cost of non-resistant seed varieties?..................................

Thank you!

APPENDIX 2: EXPERT OPINION SURVEY QUESTIONNAIRE

POTENTIAL ECONOMIC IMPACT OF INTEGRATED THRIPS MANAGEMENT IN FRENCH BEANS AND TOMATO IN KENYA

INTRODUCTION TO THE RESPONDENT

Hello, my name is Esther Achieng' and I am part of the research team at the International Centre of Insect Physiology and Ecology (ICIPE), required to evaluate the potential economic impact of an IPM (Integrated Pest Management) developed to deal with thrips in French beans and tomato. This is in partial fulfillment of my MSc. degree at the University of Nairobi. Note that the information offered herein shall be confidential and crucial in employing the economic surplus model.

Name of Respondent (Optional): ....

Date: ....

Institution:..

Contact:..

1. Do you know thrips?

   1 = Yes □ 0 = No □

2. If yes, how would you rate thrips on tomato and French beans?

1= Not a pest 2= Minor pest 3= Occasional pest 4=Major pest

3. ICIPE is proposing IPM with the following components.

   - Effective monitoring of the thrips using visual and kairomonal traps
   - Application of entomopathogenic fungi and/or botanicals
   - Intercropping with maize
   - Use of host plant resistance
   - Conservation biological control.

   Do you know of how one or all of the above IPM components would affect yield?

1 = Yes □ 0 = No □

4. If yes, which components and how?

Component	**Yield change (%)**
Effective monitoring of the thrips using visual and kairomonal traps	
Application of entomopathogenic fungi and/or botanicals	
Intercropping with maize	
Use of host plant resistance	
Conservation biological control.	

5. What do you think would be the success rate or the probability that IPM thrips will achieve the expected yield? a).Pessimistic:................. b). Most likely:.................. c).Optimistic:................. (Please fill all the three levels in %ages.)

6. How many years do you think it would take farmers to adopt this technology?.........................

7. What would be the adoption level of the above technology?..................................%.

8. For how many years would the famers adopt the technology?.................................

9. What would be the rate of annual depreciation of the technology (expected annual reduction in yield)........................%.

Thank you!

APPENDIX 3: COST OF CONTROLLING THRIPS USING PESTICIDES ON TOMATO

Nursery stage

Variable	Obs	Mean	Std. Dev.	Min	Max
areatreated	149	.0025718	.0205043	.0002	.25
frequency	149	2.57047	1.573664	1	8
costoflabo~s	149	493.6913	356.1334	60	3000
amountmls	149	224.5503	865.648	3	8000
costkshsltr	149	2378.523	1075.735	580	7000

Transplanting stage

Variable	Obs	Mean	Std. Dev.	Min	Max
areatreated	159	.6533019	.5084189	.125	4
frequency	160	3.8625	1.485729	0	12
costoflabo~s	159	705.9119	775.6666	200	7200
amountmls	159	396.4088	933.6778	5	7000
costkshsltr	159	2221.195	1132.487	180	8000

Flowering stage

Variable	Obs	Mean	Std. Dev.	Min	Max
areatreated	161	.6607143	.5164158	.125	4
frequency	161	3.950311	1.72047	1	14
costoflabo~s	161	815.3789	1130.061	250	9600
amountmls	161	425.3416	907.9113	4	6000
costkshsltr	161	2284.814	1274.962	270	10000

Maturity stage

Variable	Obs	Mean	Std. Dev.	Min	Max
areatreated	159	.6595912	.5188138	.125	4

frequency	159	3.842767	1.520054	1	14
costoflabo~s	159	807.3962	1224.488	200	12000
amountmls	158	583.1076	1331.006	5	8000
costkshsltr	159	2274.906	1405.187	270	10000

APPENDIX 4: COST OF CONTROLLING THRIPS USING PESTICIDES ON FRENCH BEANS

Planting to 3-leaf formation

Variable	Obs	Mean	Std. Dev.	Min	Max
areatreated	131	.4620229	.3399569	.125	3
frequency	131	3.221374	1.145493	1	10
costoflabo~s	131	437.4656	298.3673	50	3000
amountmls	131	59.40458	133.2038	5	1000
costkshsltr	131	2190.076	1076.197	600	7000

3-leaf to flowering

Variable	Obs	Mean	Std. Dev.	Min	Max
areatreated	131	.4620229	.3399569	.125	3
frequency	131	3.48855	.8168082	1	8
costoflabo~s	131	504.5802	422.4994	100	3600
amountmls	131	95.1374	283.6051	5	2000
costkshsltr	131	2286.489	1012.809	340	7500

Flowering to harvesting

Variable	Obs	Mean	Std. Dev.	Min	Max
areatreated	131	.4620229	.3399569	.125	3
frequency	131	3.572519	1.109612	1	12
costoflabo~s	131	545.8779	485.6215	80	3600
amountmls	131	173.458	504.4902	5	3000

costkshsltr	131	2313.969	1148.63	580	8000

Start to end of harvesting

Variable	Obs	Mean	Std. Dev.	Min	Max
areatreated	130	.4578846	.3379434	.125	3
frequency	130	3.561538	.9645166	1	8
costoflabo~s	130	542.7692	485.3521	80	3600
amountmls	130	189.4846	499.7214	5	3000
costkshsltr	130	2194.385	1033.863	480	8000