Uncertainty in the Production Decisions of Smallholder Broiler Producers in Musanze, Rwanda

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ABSTRACT

Uncertainty is a vital component of decision-making for any business. A project in the district of Musanze in Rwanda introduced new income streams and sources of nutrition for households in the form of smallholder, household broiler operations that produce 100 chickens. Prices and poultry production data were gathered from the operations.

This information was used to calibrate a stochastic financial analysis model. By incorporating field data into the model, Monte Carlo simulations were performed based on the market price, input, and production data collected over an eight-month period. Historical price index data and Brownian motion were used to simulate twenty years of future prices. The forecasted inflation rates were used to vary prices for prices in the future in the calculation of net present values (NPV) and modified internal rates of return (MIRR), producing a distribution of potential outcomes that allowed for analysis of six production scenarios.

The analysis found that selling manure produced by the broiler operations provided the greatest improvement to NPV and MIRR and was found to be first degree stochastic dominant (FDSD) over the baseline scenario and is risk efficient when compared by MIRR. Additionally, purchasing additional day-old chicks (DOC) to safeguard against chick mortality and selling the manure produced by the smallholder broiler operations are FDSD when compared to the baseline strategy by NPV and MIRR and are risk efficient strategies when compared by MIRR. The analysis also found that extending the grace period before paying for technical services was FDSD over the baseline scenario, but that gains did not justify altering the production strategy. Contract pricing of broilers was found to be risk efficient when compared to market price, or a mix of market and contract pricing by MIRR, but mean NPV for contract pricing was lower than the other two scenarios.

TABLE OF CONTENTS

CHAPTER I: Introduction ……..1
1.1 Purpose and Objectives ……5
CHAPTER II: Literature Review……7
2.1 Introduction…..…….. 7
2.2 Cost Benefit Analysis: An Overview..…… 7
2.3 Financial Analysis…..…… 7
2.4 Consumer Price Index Time Series……...10
2.5 Risk Analysis…….... 10
2.5.1 Mean-Variance ……11
2.5.2 Stochastic Dominance……...12
2.6 Summary……..14
CHAPTER III: Conceptual Framework for Analysis……...16
3.1 Cost Benefit Analysis…… ..16
3.2 Risk…… ..20
3.3 Simulating Inflation…..…… ..21
CHAPTER IV: Data Description……..22
4.1 Scale……22
4.2 Investment Costs ……24
4.3 Labor……25
4.4 Operating Costs……26
4.5 Production……28
4.6 Macroeconomic Data ……..29
CHAPTER V: Methods and Procedures ……30
5.1 Financial Analysis Model …..……..30
5.2 Simulation……33
5.3 Calibration …….....34
5.4 Scenarios……..35
CHAPTER VI: Results…….. ...39
CHAPTERVII: Conclusion ……....45
REFERENCES …….....50
APPENDIX……54
Tables……..55
Figures……63
VITA ……73

LIST OF TABLES

Table 1. Poultry Producers Across Provinces of Rwanda ……55
Table 2. Variables Used in Baseline Financial Risk Analysis Model ……..56
Table 3. Scenarios Compared in the Risk Analysis of Smallholder Broiler Operations ……..57
Table 4. Sensitivity Analysis of Grace Period for Producer Payment for Technical Services Effect on Mean Net Present Value (NPV) over 500 Iterations ……58
Table 5. Comparison of Average Profits from Musanze Operations and Real Net Cashflows Before Financing from Calibrated Financial Model ……58
Table 6. Summary Statistics of Deterministic Inflation and Stochastic Inflation (baseline) Scenarios (S0 and Baseline, respectively) ……58
Table 7. Summary Statistics of Stochastic Inflation (baseline) and Assumed Mortality (S1) Scenarios ……59
Table 8. Results of Stochastic Dominance Analysis of Production Scenarios for Smallholder Broiler Producers in Musanze, Rwanda (Baseline, S1, S2, S3, S4, and S5) …..……...59
Table 9. Results of Kolmogorov-Smirnov (KS) Tests for Distribution Equality Between Scenarios ……..60
Table 10. Summary Statistics of Stochastic Inflation (baseline) and Delayed Technician Payment (S2) Scenarios ……..60
Table 11. Summary Statistics of Stochastic Inflation (baseline), Market Price of Broilers (S3) and Contract Price of Broilers (S4) Scenarios..……61
Table 12. Summary Statistics of Stochastic Inflation (baseline) and Sell Manure Scenarios (S5) ……61
Table 13. Summary of Results from Risk Analyses of Production Scenarios for Smallholder Broiler Producers ……...62

LIST OF FIGURES

Figure 1. Coop design for Smallholder Broiler Producers in Musanze Rwanda ……..63
Figure 2. Forecasted Inflation Rates for Rwanda and The United States 2016-2036 ……..….64
Figure 3. Recorded CPI Inflation Rates for Rwanda and the Unites States 1967-2016 and Forecasted Inflation Rates 2016-2036…….....64
Figure 4. Historic Price Indices for Rwanda and United States 1967-2016 and Simulated 2017-2036 with Brownian Motion ……65
Figure 5. Timeline of Planning Horizon for Smallholder Poultry Financial Model ……65
Figure 6. CDF of NPVs from Simulation of Deterministic Inflation (S0) and Stochastic Inflation (Baseline) ……..66
Figure 7. CDF of MIRRs from Simulation of Deterministic Inflation (S0) and Stochastic Inflation (Baseline) ...……66
Figure 8. CDF of NPVs from Simulation of Stochastic Inflation (Baseline) and Assumed Mortality (S1) ……67
Figure 9. CDF of MIRRs from Simulation of Stochastic Inflation (Baseline) and Assumed Mortality (S1)……67
Figure 10. CDF of NPVs from Simulation of Stochastic Inflation (Baseline) and Delayed Technician Pay (S2)...……68
Figure 11. CDF of MIRRs from Simulation of Stochastic Inflation (Baseline) and Delayed Technician Pay (S2) …..……68
Figure 12. CDF of NPVs from Simulation of Stochastic Inflation (Baseline), Market Price (of Broilers) (S3) and Contract Price (of Broilers) (S4) ……69
Figure13. Inputs Ranked by Effect on Mean Net Present Value (NPV) Resulting from the Baseline Simulation ……..69
Figure14. Inputs Ranked by Effect on Mean Net Present Value (NPV) Resulting from the Market Price (S3) Simulation……70
Figure15. Inputs Ranked by Effect on Mean Net Present Value (NPV) Resulting from the Contract Price (S4) Simulation ……70
Figure 16. CDF of MIRRs from Simulation of Stochastic Inflation (Baseline), Market Price (of Broilers) (S3) and Contract Price (of Broilers) (S4)……..71
Figure 17. CDF of NPVs from Simulation of Stochastic Inflation (Baseline) and Sell Manure (S5)…….....71
Figure 18. CDF of MIRRs from Simulation of Stochastic Inflation (Baseline) and Sell Manure (S5)……72

LIST OF ACRONYMS

ASAP	Africa Sustainable Agriculture Project
CDF	Cumulative distribution function
CPI	Consumer price index
DOC	Day-old chick
DPB	Discounted payback period
FCR	Feed conversion ratio
FDSD	First degree stochastic dominance
HJM	Heath-Jarrow-Morton
IRR	Internal rate of return
KS	Kolmogorov-Smirnov
MINAGRI	Ministry of Agriculture and Animal Resources
MIRR	Modified internal rate of return
MV	Mean-variance comparison
NPV	Net present value
NR	Net returns
PDF	Probability density function
RMI	Risk management instruments
RwF	Rwandan franc
SCF	Seasonal climate forecasting
SD	Stochastic dominance comparison
SDSD	Second degree stochastic dominance
TI	Feet the Future Tworore Inkoko, Twunguke

CHAPTER I: INTRODUCTION

There is an opportunity for investment and growth in the broiler poultry production industry in Rwanda that could result in increased household income and access to additional sources of protein. The Government of Rwanda is pursuing an initiative to improve the country's economic well-being called Vision 2020 (Republic of Rwanda, 2012). Two issues the initiative addresses are poverty and malnutrition. Nearly 40% of Rwandan households are impoverished and malnourished, with most of these households located in rural areas (NISR, 2015). The United States Agency of International Development's (USAID) Community Health and Improved Nutrition (CHAIN) project finds that access to nutrition depends largely on household income and availability of multiple types of foods (USAID, 2016). A measure used by the USAID is a diet of "minimum diversity", which is achieved when an individual consumes five out of ten food groups within twenty-four hours. The Feed the Future Rwanda Smallholder Farmer Broiler Alliance, which includes the University of Tennessee Institute of Agriculture (UTIA), the African Sustainable Agriculture Project (ASAP), Zamura Feeds (a private Rwandan poultry company) and USAID addresses the Vision 2020 goals by supporting the development of private, for-profit poultry producers through a combination of training and investment loans through the Feed the Future Tworore Inkoko, Twunguke (TI) project. The goal of this collaboration is to address poverty by increasing household income and reducing malnutrition through the production, consumption, and sale of poultry (International Programs, 2017). The pilot program operates in the Musanze District, Northern Rwanda. Musanze was chosen because it has a poverty rate similar to other rural areas of Rwanda. The Musanze District is also home to an animal feed mill.

The producers participating in the TI project are located across 3 sectors of the Musanze District. They are self-selected by attending an information session in their community and are then drawn randomly from a list of attendees to be invited to training. Producers are then screened and must complete a 3-day classroom and hands-on training at Zamura's broiler demo farm. They must also pass a competency exam before they can receive a coop and their first cycle of birds. The coops that are provided by the project as part of the investment loan are 100 square feet (10'x10') and house 100 birds at 1 square foot per bird (Figure 1). Groups of about 30 producers start their 9-week production cycle together. The starting dates for those groups are staggered so that new groups are starting each week. The project aims to have 750 producers participating by the end of 2019 (International Programs, 2017).

In developing nations, development of the agricultural sector leads to economic growth for two reasons. First, agriculture is labor intensive relative to other economic sectors. Therefore, investment in agriculture leads to greater employment opportunity, leading to additional income and spending, further stimulating economic growth. The second reason is that increased agricultural production results in more food being available for poorer households, as well as opportunities for export (Mellor, 1976). Of the agricultural sectors in Rwanda, Rwanda's Ministry of Agriculture and Animal Resources (MINAGRI) identified the poultry sector as one with high growth potential. Rwandans consume less than half of the meat that developed countries do on a per capita basis. Rwanda's 2012 *Strategic Investment Plan to Strengthen the Poultry Industry* states that women, children, and poorer smallholders benefit more from higher income and welfare status when raising livestock than the rest of the population (MINAGRI, 2012). Therefore, expanding the poultry sector is a way of stimulating growth for the most vulnerable populations (Assa, 2012).

Rwanda is divided into five provinces. The Central Province includes Kigali, the capital of Rwanda. The Central Province has the highest number of broiler farms and birds (Table 1) (Leding and Miller, 2013). The broiler industry is most concentrated on a bird per area scale in the Central Province. The concentration of broiler production combined with the infrastructure of the capital and largest city in Rwanda means the Central Province does not have the transportation and logistical obstacles facing more rural regions. Musanze is located in the North Province, which is dominated by layer operations (Leding and Miller, 2013). The presence of non-broiler poultry operations is evidence that infrastructure exists to support the delivery of inputs and transport of birds to markets. The Eastern Province has the second highest concentration of broilers, while the Southern and Western Provinces are similar with respect to the number of broilers produced. The Western Province produces about a third of its birds as broilers, while the Southern Province's broilers make up about one-sixth of their total production of chickens (Leding and Miller, 2013).

Zamura Feeds is one of the three animal feed producers in Rwanda, operating at a daily production of 40 metric tons of poultry, swine, and dairy feed per day (Zamura Feeds, 2018). This feed mill is a key element of efforts to develop Musanze's private broiler production sector, providing start-up equipment and logistical support to growers. The costs of these services are repaid at zero-interest as a portion of grower profits. The feed mill also delivers feed and ensures marketing channels by identifying buyers. Currently, most day-old chicks (DOC's) come from a private hatchery. However, the quantity of DOC's available from this vendor is variable. There are other DOC vendors in the region, but the product quality is inconsistent and per-unit DOC prices are typically higher.

The success of a household broiler operation depends largely on the grower returns on investment. The greater the cash flow, the higher the likelihood that an operation will recuperate investment costs and generate profit. A financial and economic cost-benefit analysis was performed by Jenkins et al., (2016). The financial and economic cost-benefit analysis is exemplary, providing insight to the structure of Rwanda's growing poultry industry. In addition, the report estimates net present values of smallholder broiler operations by calculating the future prices of inputs and sales prices of broilers using consumer price indices that increase from the investment period to the first year of operation, and then remain constant over the twenty-year project horizon (Figure 2) (Jenkins, et al., 2016). This price series is one of a potentially infinite number of realizations that could depict the evolution of input and broiler prices over a fixed planning horizon. In addition, a quick examination of the historical series of price indices suggests one might expect spikes and troughs to occur randomly over time. This behavior is evident, examining the past fifty years of Rwandan and U.S. consumer price indices (Figure 3) (Worldbank, 2017).

The stakeholders in this research are smallholder broiler producers in Musanze, Rwanda. These are producers who raise chickens for meat, currently producing 100 birds at a time, though the operations may scale up production in the future to 1,000 birds at a time and still be considered small scale producers (Jenkins, et al., 2016). If a producer was to make an investment decision about their production assuming that prices will always increase over time, in the absence of uncertainty or volatility, they are vulnerable to miscalculation, possibly resulting in a less desirable (unprofitable) outcome. When evaluating an operation's present value of future cashflows based on a single state of nature (i.e. constantly increasing prices), only one present value is calculated. A producer may judge the investment opportunity based on that

simple realization. However, states of nature depicting inflation rates and price changes are infinite. Evaluating the present value of future cashflows for many possible future price series results in a distribution of present values from which more informed investment decisions can be made. When comparing options of production decisions such as the scale of the operation or adopting new input purchasing strategies, one alternative may be more responsive to changes in inflation than others. Having distributions of values to compare as opposed to comparing a single outcome for each scenario allows the producer not only to see a single potential outcome of the operation, but a range of potential outcomes and the probability of the outcome being above or below a target value (Roy, 1952).

Without knowledge of the distribution of expected outcomes and the probability that each event will occur, it is difficult for producers to make informed decisions about insurance, capital reserves, or strategies to leverage assets for other investment opportunities (Hardaker, et al., 2015). Neglecting to address uncertainty leaves decision-makers vulnerable to downside risk or lower payoffs if conditions turn out to be different than expected. Conversely, not accounting for price volatility and production uncertainty might lead some smallholders to be overly conservative in their investment and production decisions, operating at a lower scale than they might if they had information about the variance of expected returns, i.e. risk (Hardaker, et al., 2015).

1.1 Purpose and Objectives

This research develops a risk analysis tool to analyze the expected value and variance of returns associated with production strategies used by small scale broiler producers in Musanze, Rwanda. The research objectives are:

1. To estimate net present values and modified internal rates of return for different smallholder broiler production technology combinations using stochastic forecasts of inflation rates while accounting for the variability in costs of production, market prices, and production uncertainty.
2. To conduct risk analyses based on stochastic cost and price series.

CHAPTER II: LITERATURE REVIEW

2.1 Introduction

This research evaluates the financial risks of smallholder broiler production in Musanze District, Rwanda with a stochastic cost-benefit analysis. The objectives of the cost-benefit analysis, as well as the measures used and the process by which they are calculated and evaluated, are summarized in this chapter along with the methods used in the risk analysis.

2.2 Cost Benefit Analysis: An Overview

In *The Economic Analysis of Agricultural Projects* by J. Price Gittinger (1982), a project consists of five steps: identification, preparation and analysis, appraisal, implementation, and evaluation. The cost-benefit analysis conducted in this research focuses on current smallholder broiler operations, making this cost-benefit analysis an evaluation of the operations (Gittinger, 1982). As Gittinger states, the evaluation of ongoing projects provides an opportunity to identify potential strategies to improve and strengthen the project.

A general objective of cost-benefit analysis, as described by Boardman et. al., is to allocate resources to their most efficient use (Boardman, et al., 2001). In this analysis, the producer's objective is to maximize expected profits over a planning horizon. The measures used to evaluate profits over multiple production cycles are net present value (NPV) and internal rates of return (IRR).

2.3 Financial Analysis

This analysis determines the feasibility and profitability of a smallholder broiler operation over a twenty-year planning horizon. The measures by which profitability is analyzed include costs and benefits from future periods as well as the initial investment period. The time value of

money principle states that one dollar today is worth more than a dollar in the future. This difference in a dollar's worth across time periods is due to the opportunity cost of potential investment and foregone revenues that could have been generated with that dollar between current and the future periods (Gittinger, 1982). The bottom-line value used to measure discounted future periods is the net present value.

The IRR is useful for comparing multiple projects. The IRR measure enables the decision maker to rank projects. The decision-maker prefers a project that recovers investment cost and generates profit at a higher cost of capital rate than other projects. The IRR is used in this analysis to compare project scenarios. The IRR is determined by calculating the project's NPV and changing the cost of capital (*i*) until the NPV equals zero. The IRR therefore indicates how high the cost of capital could be without generating a negative NPV (Asqutth and Bethel, 1995).

The IRR has shortcomings. Namely, the IRR assumes that reinvestment is being made from one period to the next at an interest rate or cost of capital equal to the IRR being calculated. This is unrealistic because an investor is typically not restricted to only invest in projects that have the same returns as their cost of capital (Harvard Press, 2004). If this were the case, the decision-maker would not invest because any gains would be negated by the loss on interest of the money they use to invest. Another limitation of the IRR is that when cash flows move from negative in one period to positive in the next period multiple times over the course of a project, it is possible that there could be more than one IRR that drives the NPV to zero without indication which might be the true IRR (Kierulff, 2008). An example of the IRR's inability to provide a single solution was given when determining the financial feasibility of a pig fattening investment in Siberia that had three non-consecutive years with negative cashflows (Ivanović, et al., 2015). The numerical solution to resolve the issue used by Invanovic et al. (2015) was the modified IRR

(MIRR), which indicated that the investment would be profitable so long as the cost of capital was less than or equal to 17%, which was well above the rate estimated in the study.

Satyasai (2009) used a time-adjusted MIRR was used in an *ex post* evaluation ranking watershed projects by their rates of return on investment. Satyasai found that projects appeared less lucrative when evaluated with MIRR than with IRR. The rankings determined with the MIRR were consistent with rankings determined with IRR and NPV. However, the ranking of projects was different when the time adjusted MIRR was used.

An analysis of different forms of investment for raspberry plantations on rural households that noted different technological, organizational, and economic dynamics of investments as well as different financing options for those investments used MIRR as well as NPV and payback period to determine the feasibility of investments (Gogić and Ivanović, 2013). The analysis found that both models examined were feasible, and that it was better to establish the plantation all at once as opposed to gradually implementing it on the property. The MIRR was found to be over 10.5% for each model which is greater than the cost of capital of 8% that was used.

An analysis of risk for different irrigation technologies used the MIRR in addition to NPV and payback period to evaluate operations using five different technologies, including two that used no irrigation and three that used different types of irrigation (Aredes, et al., 2007). The analysis found that risk was reduced by using any of the three irrigation methods by reducing payback period and increasing economic return.

There are three steps to calculate the MIRR. First, remove any excess investment rate from projected net benefits, then replace them with the lowest rate expected over the course of the project, and finally use the rate that is reasonable to expect to obtain on investments throughout

the project to calculate the IRR (Kierulff, 2008). The MIRR can be calculated in most software supporting financial functions.

2.4 Consumer Price Index Time Series

This financial analysis depends on cash flow estimates, and therefore future prices (not to be confused with "futures"). The assumption that prices in the future reflect proportionally the same relative prices, will result in the best estimation of future prices (Gittinger, 1982). The task is to determine what relative prices may change, and how overall prices are likely to fluctuate during the life of the project. Beyond the basic principal of relative prices, Gittenger (1982) suggests using increasing prices. However, the increasing price strategy is less effective than it once was because inflation has displayed less of a prominent trend over recent decades (Reed, 2014). Boardman et al. (2001) suggest using consumer price indices as a way to track price movements, but they caution that CPIs tend to over-state inflation (Boardman, et al., 2001).

The Heath-Jarrow-Morton (HJM) method for simulating interest rate behavior has been applied to the simulation of inflation and expounded upon by Heath et al. (1992), Jarrow and Yildirim (2003), and Mercurio (2005). These inflation option pricing models incorporate of Brownian Motion to capture the randomness of inflationary trends over time (Waldenberger, 2017). Brownian motion is used to simulate future CPI values for the smallholder broiler operations in this thesis (Figure 4).

2.5 Risk Analysis

Hardaker et al. (2015) define risk as a situation in which an individual knows possible outcomes and their respective probabilities of occurring, whereas uncertainty as a situation in which the probabilities of each outcome are unknown. Thus, taking on a risk is a decision that

could result in a suboptimal outcome because each outcome has some probability of occurring and some outcomes are preferable to others (Hardaker, et al., 2015). In the case of a project investment, such as smallholder broiler production, there are many possible outcomes that can be ranked from most profitable to least because profit generation is the main goal of each coop.

2.5.1 Mean-Variance

Markowitz (1952) introduced the mean-variance efficiency criterion for ranking investment portfolios based on a combination of their expected returns (mean) and their level of risk (variance) (Markowitz, 1952). Investments with a higher mean and lower variance are comparatively risk efficient and preferred over others by a risk neutral decision maker. Symbolically,

$$\text{if } \mu_A > \mu_B \text{ and } {\sigma^2}_A \leq {\sigma^2}_B, \text{or } \mu_A \geq \mu_B \text{ and } {\sigma^2}_A < {\sigma^2}_B, \text{then } A \succ B \qquad (1)$$

where μ_x is the mean of X, ${\sigma^2}_x$ is variance of X, A and B are alternatives being ranked. If either mean or variance do not exhibit a strict inequality, the alternatives can still be ranked. However, if one project has a higher mean but also a higher variance than the other, the two alternatives cannot be ranked by this method. Aside from possibly leaving alternatives unranked, this criteria assumes that outcomes are symmetric and normally distributed (Markowitz, 1952).

The mean-variance efficiency criterion has been used to evaluate hedging strategies for cattle feeding operations (Holland, et al., 1972). The study recorded the mean and variance of net returns for operations using strategies including not hedging at all, hedging all of their cattle all the time, and five other strategies that hedged under certain circumstances. The study found that all hedging strategies were efficient compared to the unhedged strategy. The research also determined that a strategy of seasonal hedging with price adjustments and a strategy that

considered expected net revenue as part of the decision rule for hedging were efficient compared to the other five strategies.

Mean-variance efficiency method was compared with expected utility methods using two different utility functions to evaluate price hedging decisions for hog producers in a simulation analysis that evaluated different price scenarios over two levels of risk aversion. For example, Garcia et al. (1994) determined that mean-variance was useful in this context as both methods identified the optimal strategies in a large percentage of cases.

Collins and Gbur (1991) assessed how limited liability affected institutions' decision making in risky situations used mean-variance criteria as well as other decision making methods to evaluate which methods were consistent with the utility maximization of limited liability institutions. This study found that the results of mean-variance criterion was consistent with the institutions' utility maximization behavior only under a limited set of circumstances regarding the utility function, distribution of terminal wealth, and parameter assumptions.

Perry et al. (1989) examined how well the mean-variance method performed using estimated data rather than historic data to inform crop mix decisions. By comparing the mean-variance criteria with other methods, they determined that mean-variance rankings were still accurate when using simulated data.

2.5.2 Stochastic Dominance

Stochastic dominance (SD) is a way of ranking risky alternatives by the comparing cumulative distributions of their outcomes. The stochastic dominance method does not require assumptions about the decision-maker's utility function, but does require assumptions about the decision-maker (Hadar and Russell, 1969). Assumptions made about the decision-maker are: (i)

they prefer more to less and (ii) they prefer to avoid lower-value outcomes (Lambert and Lowenberg-DeBoer, 2003). Assumption (ii) omits higher-value outcomes as most people enjoy the up-side variability of typical outcomes being measured such as profits and yields. First degree stochastic dominance (FDSD) only assumes that the decision-maker prefers more rather than less. If one cumulative distribution function (CDF) lays entirely below or to the right of another, the distribution to the right dominates the other one as that alternative results in a higher outcome at every probability level compared to the other alternative. Another way to say this is that for alternatives *A* and *B* with CDF's $F_A(x)$ and $F_B(x)$, respectively, if:

$$F_A(x) < F_B(x) \tag{2}$$

then alternative *A* dominates alternative *B* (Mas-Colell, 1995).

Second degree stochastic dominance (SDSD) assumes the decision maker is risk averse. A measure of the potential an alternative has for a low outcome is the area under the CDF for that alternative. An alternative is dominant over another if the area under its CDF is smaller at every level of outcome. With SDSD, the CDF's may cross. Whichever lies to the left of the other where they intersect the horizontal axis cannot be the dominant alternative as the chance of loss is greater with that alternative. If the CDF to the right where they intersect the horizontal axis has greater area between it and the other CDF below their intersection than above, then that alternative dominates (Lambert and Lowenberg-DeBoer, 2003).

A study was conducted to determine the values of experimental varieties of wheat for growers and end-users while considering variability in economic, agronomic, and quality variables (Dahl, et al., 2004). Stochastic dominance was used to determine efficient technology

sets and found that two experimental varieties of hard red spring wheat were efficient compared to existing varieties in the market.

Stochastic dominance was used to compare the income of cotton growers in Australia who adjusted plant area in response to seasonal climate forecasting (SCF) compared with the incomes of growers who ignored SCF (Ritchie, et al., 2004). The study found that significant gains can be had from minimizing risk by adjusting plant area in response to SCF. The study also noted that the farmers' exact response to the SCF varied depending on their attitudes towards risk.

For two regions in Germany, efficient production options of apple producers were determined and risk management instruments (RMI) were identified through stochastic dominance criteria (Rohrig, et al., 2018). Red prince was determined to be the most efficient variety for northern producers where subsidized hail insurance with frost irrigation was found to be superior to frost irrigation alone. Braeburn was determined to be the efficient variety for southern producers where producing apples under hail nets was found to be more efficient than any of the tested insurance solutions for producers.

Risky alternatives regarding greenhouse investment decisions for tomato growers were ranked using stochastic dominance among other methods (Asci, et al., 2014). The study found that it would be more risk efficient for growers to continue growing their tomatoes in a field rather than invest in a greenhouse and identified types of policies or market conditions for which greenhouse production would become preferable.

2.6 Summary

The analysis of the smallholder broiler operation utilizes a cost-benefit analysis that evaluates the outcomes of the project via net present values and modified internal rates of returns

which are calculated using discounted prices in the future that are estimated using consumer price indices to incorporate inflation across all prices. The simulation of these indices is performed using a Brownian Motion formula. The risk analysis uses different criteria for various constraints placed on the simulation including mean-variance criteria, and stochastic dominance.

CHAPTER III: CONCEPTUAL FRAMEWORK FOR ANALYSIS

3.1 Cost Benefit Analysis

The objective of this cost benefit analysis is to evaluate the profitability, rate of return, and riskiness of smallholder broiler operations. Net returns (NR) to the smallholder broiler operation are defined as:

$$\widetilde{NR} = \tilde{P}_{Br} * \tilde{Q} - \tilde{C} \quad (3)$$

where P_{Br} is per live Kg price of a broiler, Q is the quantity of broilers sold, and C is cost of the operation. Stochastic variables are denoted by the tilde (~).

Broiler prices are denominated as Rwandan Francs (RwF) per live Kg received by the smallholder. The smallholders in this study typically sell an entire flock at one price. However, it is common for broiler prices to vary from one flock to the next because each sale is negotiated individually.

The quantity of broilers sold is recorded as total Kg of live birds sold by the smallholder. This value varies from flock to flock because of the variability in the mortality of day-old chicks purchased and feed conversion ratios (FCR), or the amount of feed necessary to produce a given unit of body weight (Wenk, et al., 1980). FCR is affected by feed quality, temperature, and genetics.

Total costs of production are measured in RwF, and calculated as:

$$\tilde{C} = FC + \widetilde{VC} \quad (4)$$

The parameter FC are fixed costs:

$$FC = v_1 + v_2 \tag{5}$$

where v_1 are general maintenance costs and v_2 is the annual depreciation of buildings. The symbol *VC* are variable costs, calculated as:

$$\widetilde{VC} = \widetilde{u_1} + \widetilde{u_2} + \widetilde{u_3} + \widetilde{u_4} + u_5 + u_6 + u_7 + u_8 \tag{6}$$

where u_1 is the cost of the heating source (charcoal), u_2 is the cost of water, u_3 are feed costs, u_4 the cost of vaccines, u_5 the cost of day-old chicks, u_6 are bedding costs, u_7 the cost of labor, and u_8 disinfectant cost (Jenkins, et al., 2016).

If any component of a revenue or cost term is stochastic, then that variable is itself stochastic. Thus, operation costs are stochastic because the variable and fixed costs on the right-hand side of the operation cost calculation are stochastic. In this analysis, charcoal, feed, vaccine, and water are stochastic costs for the smallholder broiler operation. Each of these inputs are vulnerable to local variations in prices. Additionally, the amount of charcoal used for a flock varies depending on the outside temperature during the production cycle and charcoal quality.

The net present value (NPV) is the value of the entire project over a time horizon, including initial investment and the expected benefits and costs in future periods throughout the life of the project in today's money. The NPV is calculated for the life of the project; therefore, multiple time periods typically need to be considered. The present value of net returns for future periods is calculated as:

$$NPV = -C_{Inv} + \sum_{t=1}^{k} \frac{NR_t}{(1+r)^t} + T(k) \tag{7}$$

where; C_{Inv} is the cost of investment; r is the interest rate; t the time period from the first production period ($t = 1$) to the end of the project ($t = k$); and k the number of periods over which the operation is assessed. The terminal value, $T(k)$, is the salvage value of equipment and buildings if the project were to be shut down and liquidated (in this case, after 20 years). In this analysis, the terminal value is calculated as:

$$T(k) = w + z \tag{8}$$

where w is the salvage value of the coop and z the salvage value of equipment used in the broiler operation at the end of the 20-year planning horizon.

The planning horizon of 20 years was chosen because that should be enough time to recover investment expenses and/or repay a commercial investment loan, and that time period is long enough that reinvestment of buildings (every 10 years) and equipment (every 4 years) are incorporated into the model (Figure 5). Though the reinvestment in buildings and equipment is considered a best practice according to Jenkins et al. (2016), real world producers are less likely to reinvest in equipment according to the best practice schedule which means that the NPV and MIRR values calculated by the model are conservative.

The NPV captures the present value of net returns over the life of the operation. Risk neutral producers prefer projects generating the highest NPV. For risk-neutral producers, the variance of NPV is unimportant. Therefore, multiple production scenarios can be modeled and their respective NPV's compared to determine which alternative would be preferred by a risk neutral producer.

Another measure that can be used to assess an operation's profitability is the modified internal rate of return (MIRR). This indicator is the interest rate that drives the NPV to zero.

The MIRR allows for both cost of capital and reinvestment interest rates, and corrects for the inaccuracies of the of the internal rate of return (IRR) which compounds when cashflows turn negative to positive between periods multiple times (Kierulff, 2008). The MIRR is calculated by altering the interest rate used in the NPV calculation until the NPV reaches zero. Similar to NPV comparisons, the MIRR can be used to compare results generated under different production scenarios. Risk neutral producers always prefer projects that yield higher MIRRs.

Chance of loss, or the probability that the operation will realize a zero or negative NPV over the planning horizon, is another way in which the operations are evaluated (Hardaker, et al., 2015). The probability on the CDF resulting from a simulation that corresponds with an NPV of zero is the probability that the operation will have an NPV of zero or less. This probability is the chance that the producer can expect to not see any profit beyond recovering the investment cost (in the case of an NPV of zero), or not even recovering their investment (in the case of a negative NPV). Therefore, the lower the chance of loss, the better.

Another method used to evaluate the operation is the discounted payback period (DPB). The DPB is the time (in years) that it takes the operation to recover its investment cost when considering the time value of money (Marlow, 2015). This is done by simply subtracting investment costs from the present value of net returns and determining the time period in which NPV turns positive. The distribution of DPBs from the simulation provide probabilities of achieving DPBs of a certain value, i.e. the probability of DPB being less than or equal to 5 indicates what chance the producer has of recovering their investment costs and turning a profit within the first 5 years. The probability of DPB being less than or equal to 5 years is valuable information for someone who might be interested in operating a coop for 5 years instead of the 20 year planning horizon used in the financial model.

3.2 Risk

Stochastic dominance (SD) and mean-variance criteria (MV) are used to analyze the risk associated with different production scenarios. These criteria are used to rank the scenarios according to risk efficiency. For SD, the distributions of NPVs and MIRRs generated from the Monte Carlo simulation are used. The distributions were evaluated to determine first and second degree stochastic dominance with a spreadsheet model developed for research conducted by Lambert and Lowenberg-Deboer (2003). The two-sample Komolgorov-Smirnov (KS) statistical test provides additional information about the distributions by providing the maximum vertical distance between the two CDFs being compared (D-statistic), and provides a statistical significance level to determine whether or not to reject the null hypothesis that the distributions are equal:

$$\mathrm{H}_0: F_A(x) = F_B(x) \tag{9}$$

(Heshmati and Rudolf, 2014). Scenarios were evaluated by the KS test using STATA©/IC 15.0 (StataCorp, 2017).

The variables of the broiler production previously listed as stochastic are varied during each Monte Carlo draw. The simulations generate distributions that can be statistically compared and analyzed. For the financial analysis, the mean values of these distributions, as well as the chance of loss, can be compared under different production scenarios to rank scenarios.

The MV compares mean and variance values for NPVs and MIRRs of each scenario. Scenario A is considered risk efficient compared to scenario B if the mean of the measure being

evaluated is higher for A than for B, and the variance or standard deviation is lower for A than for B.

3.3 Simulating Inflation

The simulation varies a price index in order to calculate prices in real terms with an inflation rate (assuming that all economic prices in all sectors maintain their relative relationships to one another and vary together over time). The inflation rate is calculated as a function of simulated consumer price indices (CPI's). Simulating future inflationary trends uses a standard Brownian Motion process around a mean (μ), standard deviation (σ), and a drift coefficient (δ_t) based on the percentage change in historic CPI data from Rwanda (Jarrow and Yildirim, 2003). An inflation rate with Brownian motion (*Inf*) is calculated as:

$$\widetilde{Inf_t} = \widetilde{Inf_{(t-1)}} \cdot \left(1 + \mu \cdot \delta + \sigma \cdot \sqrt{\delta}\right) \cdot \tilde{\gamma} \tag{10}$$

where γ is a normal random variable with mean zero and a standard deviation of 1. The drift coefficient is calculated as:

$$\delta = \frac{1}{(q-1)} \tag{11}$$

where q is the number of time series observations used to calculate the simulation (q=20 years). This allows for random movement that is bounded by the central tendencies of the variation in the observed time series of the inflation rates. CPIs are 1 for the base year (2016), and for years 2017 through 2020, are calculated as:

$$\widetilde{CPI_t} = CPI_{t-1} \cdot \left(1 + \widetilde{Infl_{t-1}}\right) \tag{12}$$

CHAPTER IV: DATA DESCRIPTION

The data used in the financial risk analysis model is compiled from three sources; 1) the smallholder broiler program in Musanze District, Rwanda, interviews conducted with producers and suppliers in the poultry industry in the Musanze area (Zamura Feeds, 2017, Lambert, et al., 2017), 2) a report conducted on the poultry sector in Rwanda (Jenkins, et al., 2016), and 3) a Worlbank.org (2017) database all contributed data used to create the variables for this model (Table 2).

Over 32 weeks (September 16, 2017 to April 23, 2018), seventy-four smallholder broiler producers in the Musanze District, Rwanda completed up to three nine-week production cycles, resulting in 125 observations of pooled production-cycle data. Investment costs, production costs, revenue, and production data were collected by technicians who provided technical advice to smallholders regarding the operation. The technicians ensured that the producers had the necessary inputs needed for broiler production. Additional information regarding the financial structure and obligations of the operation was gathered from an operating agreement between smallholder farmers and Zamura Feeds (Zamura Feeds, 2017).

4.1 Scale

Capacity of the model broiler operation is the amount of birds that the operation can handle in a production cycle (63 days) (Table 2). The capacity was obtained from the smallholders observed in Musanze and is a deterministic variable. The smallholders in Musanze are equipped with a coop (re-paid in installments at an interest rate of zero percent) and equipment sufficient to produce 100 birds per cycle.

Capacity utilization in this analysis is the percentage of production capacity used, or the amount of birds produced as a percentage of the maximum number of birds that the operation can produce at one time. Capacity utilization is a decision variable, one that the producer can control as part of a production strategy (Ragsdale, 2004). Capacity utilization is assumed to be 100% for all but the investment period (t=0) of the twenty-year planning horizon (t=0 through t=20) due to the expectation that the producer wants to maximize profit, and assuming their marginal profit is positive for each bird produced. In the investment period (t=0) no birds are produced, so capacity utilization is zero percent. In all subsequent years of the planning horizon (t=1 through t=20) producers operated at 100% capacity utilization, calculated as:

$$CU = \frac{\beta_p}{Cap} \tag{13}$$

where CU is capacity utilization, β_p is the number of birds expected to be produced, and Cap is the annual capacity of the operation (500).

The production cycle is the number of days required to grow a flock of chicks to maturity, sell the flock, and allow a cleanout period before starting another flock (Table 2). The target cycle length used by the smallholder producers in Musanze was sixty-three days, including a seventeen-day cleanout period. The cleanout period occurs after the flock is sold and before the next round of DOCs are brought into the coop, during which the coop and equipment is cleaned and disinfected to prevent the potential transfer of disease from one flock to another. That target value was used in the financial model and was treated as a deterministic variable. Thus, the production cycle could be viewed as a decision variable; however, the effects of changes in the length of the cycle on average weight of broilers sold are expected to be sizeable

and are not captured in this model. The number of cycles is calculated on a per year basis using the constant of 365 days in a year divided by the number of days in the production cycle:

$$Cyc_{Year} = \frac{365}{Cyc_{Days}} \tag{14}$$

where Cyc_{Year} is the number of cycles in a year (5 cycles). The parameter Cyc_{Year} is rounded down because only whole cycles produce broilers for sale; therefore, returns cannot be calculated for partial cycles.

Annual broiler production capacity is calculated as:

$$Prod_{Year} = Cap \cdot Cyc_{Year} \tag{15}$$

where $Prod_{Year}$ is the annual production capacity. Annual broiler production capacity is the is the number of birds capable of being produced by the operation in a year.

4.2 Investment Costs

Investment cost, measured in RwF, is the amount spent on equipment. For the Musanze program operation, this cost was the same for each smallholder and paid by Zamura Feeds as an investment loan (Table 2). Investment costs are, therefore, deterministic. Investment costs in the financial model include the costs of equipment, buildings, land, and utility installation necessary for the household to begin growing broilers.

$$C_{Inv} = Eqp + Bld + Lnd + Utl \tag{16}$$

Here, C_{Inv} is investment cost, and Eqp is the cost of equipment calculated as:

$$Eqp = \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 \tag{17}$$

where α_1 is adult feeder cost (21,600 RwF), α_2 is chick feed plates cost (10,000 RwF), α_3 is drinker cost (7,600 RwF), and α_4 is clay pot cost (3,400 RwF). The variable *Bld* is building cost, or the cost to construct the coop (485,261 RwF). The variable *Lnd* is the cost of land used for the operation, calculated as:

$$Lnd = Area_{Lnd} \cdot P_{Lnd} \cdot (1 + C_{Over}) \quad (18)$$

where $Area_{Lnd}$ is the area of land purchased for the operation, P_{Lnd} is the price of land purchased, and C_{Over} is the cost overrun factor. C_{Over} is a percentage of cost overage expected to occur on a project such as building a coop. Area, price, and cost overrun are assumed to be zero because the coops are built on the smallholder's existing property and are only 10'x10', so no additional land needs to be purchased (Figure 1). The variable *Utl* is the cost of installing utilities, such as electricity and water. Utility installation costs are also assumed to be zero because no electricity is used in the production process, and water is purchased by the liter and carried to the site.

4.3 Labor

Labor costs are classified as either skilled or unskilled. The number of skilled workers is the number of employees whose work requires a higher level of training and/or experience than unskilled positions. The number of skilled and unskilled laborers are held constant in the analysis. Because almost all of the labor necessary to run the operation is provided by the household members who's pay is in the form of profits produced by the operation, there are no paid skilled laborers, such as managers. Opportunity cost of labor for the household members working the coops were not included in the model for a few reasons. The TI project is intended to provide income opportunity for households with few wage-earning opportunities available (Programs, 2017). Worldbank (2015) reported that in 2011, Rwanda suffered from 36 percent

underemployment with the median worker working less than 26 hours per week. These operations are intended to require a small amount of labor time each day and should not prevent the members of the household from obtaining additional work if they wish. Additionally, the operation profits are compensation for the time worked by the household members. The only unskilled laborer is the technician who advises the smallholders on production matters such as the amount of feed to use or when to remove the clay pot heater from the coop. The technician also delivers inputs and picks up adult broilers to deliver them to buyers. Salary for skilled and unskilled positions are deterministic. According to the agreement the smallholders entered into with Zamura Feeds, the smallholder is required to pay the technician 11,000 RwF per cycle, starting at the fourth production cycle (Zamura Feeds, 2017). To convert this amount to RwF per month for the financial risk model, the following calculations were made:

$$UnSal_{Monthly} = UnSal_{Cycle} * \frac{30}{Cyc_{Days}} \quad (19)$$

where, $UnSal_{Monthly}$ is the monthly salary for unskilled workers in RwF, $UnSal_{Cycle}$ is the salary per cycle for unskilled workers in RwF (11,000), the number thirty (30) is the constant used for the number of days in a month, and Cyc_{Days} is length of the cycle in days (63. The salary of skilled labor (100,000 RwF) is from the financial analysis report by Jenkins et al. (2016).

4.4 Operating Costs

Operating costs consist of vaccines, slaughtering and packaging service per cycle, charcoal, water, general maintenance, liter, disinfectant, feed, and DOC costs (Table 2). Each of these variables were observed from the Musanze program operations. The stochastic variables are: vaccines, which is the cost of vaccines recorded in RwF per bird (min=8, median=8, max=24), charcoal (min=4,285, median=12,857, max=15,714), water (min=1,429,

median=1,429, max=1,667), and bedding (min=0, median=1,500, max=2,476), are recorded in RwF per month (Table 2). Feed cost (u_3 from equation 6) are measured in RwF per year, and are a function of two stochastic observed variables, average feeding per cycle ($Feed_{Cycle}$) in Kg per bird (min=2.13, median=5.75, max=8.97), the price of feed (P_{Feed}) in RwF per Kg (min=310, median=350, max=380), and the number of birds planned (β_P) in birds per year:

$$\widetilde{u_3} = \widetilde{Feed_{Cycle}} \cdot \widetilde{P_{Feed}} \cdot \beta_P \tag{20}$$

where $Feed_{Cycle}$ is:

$$\widetilde{Feed_{Cycle}} = \frac{\widetilde{Feed_{Ttl}}}{\widetilde{\beta_{Sold}}} \tag{21}$$

and $Feed_{Ttl}$ is the total amount of feed used during the production cycle in Kg (min=200, median=519, max=800).

Slaughtering and packaging service per cycle is assumed to be zero because smallholders are paid for live birds and processing costs are assumed by the buyer (e.g., the feed mill). General maintenance costs are also assumed to be zero as none were observed in the dataset. Disinfectant costs (714 RwF/Month) was assumed to be deterministic because a single bottle of disinfectant is used after each production cycle and there was no observed variation in price. The DOC cost measured in RwF (u_5 from equation 6) (min=0, median=340,000, max=340,000) is a function of birds planned (β_P) and price of DOCs (P_{DOC}) (680 RwF):

$$u_5 = \beta_P \cdot P_{DOC} \tag{22}$$

The price of DOC's is deterministic in the model because no variation was observed in the 125 observations used in this analysis, though price in more recent data has varied.

4.5 Production

Average carcass weight (Wt_{Avg}), measured in Kg per bird, is a function of the stochastic variables, total weight of the flock (Wt_{Total}) (measured in Kg), and the number of birds sold in a cycle (measured in birds):

$$\widetilde{Wt_{Avg}} = \frac{\widetilde{Wt_{Total}}}{\widetilde{\beta_{Sold}}} \tag{23}$$

The total weight and birds sold values were observed from the Musanze program operations.

Manure production and prices are included in the financial analysis because it is common for broiler operations to sell the manure produced during production for fertilizer (Jenkins, et al., 2016). Participants in the Musanze program do not currently sell their manure; therefore, value added from manure was assumed to be zero.

The realized mortality rate of the DOCs in the first two weeks is a stochastic variable, recorded in the Musanze program data. The mortality rate is the percentage of chicks purchased that did not survive past the first two weeks of the production cycle. The assumed mortality rate is a similar percentage of chicks, but is the percentage expected not to survive. In this analysis, the assumed mortality rate is, therefore, a decision variable.

The broilers sold at the farm gate (β_{Sold}) is a function of the DOCs purchased (DOC_{Purch}) and the realized mortality rate ($Mort_{Real}$):

$$\widetilde{\beta_{Sold}} = DOC_{Purch} \cdot \left(1 - \widetilde{Mort_{Real}}\right) \tag{24}$$

DOCs purchased is a function of birds planned (β_P), number of cycles (Cyc_{Year}), and assumed mortality ($Mort_{Assm}$):

$$DOC_{Purch} = \frac{\beta_P}{Cyc_{Year}} \cdot (1 + Mort_{Assm}) \quad (25)$$

Broilers at farm gate (P_{Br}) (min=1,151.52, median=1,360, max=2,219.37) is the price of broilers sold by the smallholders. This stochastic variable was observed in the data from the smallholder operations in the program in Musanze and was recorded as RwF per live kg.

4.6 Macroeconomic Data

The discount rate is the rate (17%) that future values are discounted in the calculation of the NPV and MIRR. This deterministic value is drawn from the average of monthly lending interest rates for Rwanda from July, 2016 through June 2018 (National Bank of Rwanda, 2018). The reinvestment rate, or economic cost of capital variable is equal to the discount rate (17%) and is used to calculate the MIRR.

The real exchange rate of 840 RwF to one USD ($1) was used as the rate to use for the Musanze program data in 2017 when that value was an approximate average rate over August through September of that year (XE, 2018). That exchange rate is used for all conversions of RwF to USD in this analysis.

Historic CPIs for Rwanda and the United States from 1967 through 2016 are from the Worldbank (2017) database. There were missing values for the CPIs for Rwanda from 1994 and 1995. Those values were estimated using a moving average of degree four [MA(4)].

$$CPI_t = \frac{1}{4}\sum_{i=1}^{4} CPI_{t-i} \quad (26)$$

Here, CPI_t is the CPI for time t (DeLurgio, 1997).

Deterministic values for inflation rates for Rwanda and the U.S. are from the report by Jenkins et al. (2016), and calculated as was described in equation 10 as a stochastic variable.

CHAPTER V: METHODS AND PROCEDURES

The model used in the Jenkins et al. (2016) report on the poultry industry in Rwanda calculates current and future net returns, NPVs, and MIRRs for a smallholder broiler operation using an estimated budget for the operation. This research modified that model to incorporate stochastic variables and enable simulation of different production scenarios. The financial performance of each scenario is compared using statistical analysis to identify risk-efficient production strategies.

5.1 Financial Model

Calculation of the MIRR requires multiple calculations of the NPVs. NPV calculations require C_{Inv}, k, NR_t, r, and $T(k)$, as shown in equation 7. This research uses real net cashflows after financing ($RealNCF_{AftFin}$) to determine NR_t:

$$\widetilde{RealNCF_{AftFin}}_t = \widetilde{RealNCF_{BefFin}}_t + Disb_t - Pmt_t \quad (27)$$

where $RealNCF_{BefFint}$ are real net cashflows before financing in time period t, $Disb_t$ is the loan amount disbursed to the producer in time t, and Pmt_t is the amount of loan payments made by the producer in time t. The $Disb_t$ variable for Musanze's smallholder producers is equal to C_{Inv} for time period t=0, and zero for all following periods in the planning horizon. The variable Pmt_t was calculated as:

$$Pmt_t = \left(\frac{r(C_{Inv})}{1-(1+r)^{(m-s)}}\right) \cdot \frac{1}{\widetilde{CPI_t}} \quad (28)$$

where *m* is the term of the loan (4 years) and *s* is the grace period (1 year). The term $\frac{1}{CPI_t}$ is included to convert the loan payment amount to real RwF. The variable $RealNCF_{BefFint}$ is calculated as:

$$\widetilde{RealNCF_{BefFin_t}} = \widetilde{Inflw_t} - \widetilde{Outflw_t} \quad (29)$$

where $Inflw_t$ is cash inflow at time *t*, and $Outflw_t$ is cash outflow, time *t*. The variable $Inflw_t$ is calculated as:

$$\widetilde{Inflw_t} = \widetilde{Rev_{Br}}_t + Rev_{Man}{}_t + Rsd_{Lnd}{}_t \quad (30)$$

where Rev_{Brt} is the revenue generated from the sale of broilers in time *t*, Rev_{Mant} is the revenue generated from the sale of manure in time *t*, and Rsd_{Lndt} is the real residual value of land in time *t*. The variable Rev_{Brt} is calculated as:

$$\widetilde{Rev_{Br}}_t = \widetilde{CPI_t} \cdot \widetilde{P_{Br}} \cdot \left(\beta_P{}_t \cdot \left(1 - \widetilde{Mort_{Real}}\right) \cdot \widetilde{Wt_{Avg}}\right), \quad (31)$$

and Rev_{Mant} is calculated as:

$$\widetilde{Rev_{Man}}_t = \widetilde{CPI_t} \cdot P_{Man} \cdot Prod_{Man}{}_t \quad (32)$$

where P_{Man} is the price of manure in RwF per 40 Kg bag, and $Prod_{Man}$ is the number of 40 Kg bags of manure produced during a production cycle in time *t*. Because the Musanze program participants are assumed to not sell manure, P_{Man} is assumed zero; therefore, Rev_{Mant} is zero. The variable Rsd_{Lndt} is zero for all time periods except the last time period in the planning horizon, where *t=k*. For the last period, Rsd_{Lndt} is calculated as:

$$\widetilde{Rsd_{Lnd}}_{t=k} = \widetilde{CPI_{t=k}} \cdot Lnd \quad (33)$$

Cost of land used (*Lnd*) is assumed to be zero; therefore, Rsd_{Lndt} is zero. The $Outflw_t$ variable is calculated as:

$$\widetilde{Outflw}_t = C_{Inv} + FC_t + \widetilde{VC}_t + Tax_{Local} + Tax_{Corp} \quad (34)$$

where Tax_{Local} is the local tax rate which is zero, and Tax_{Corp} is the corporate tax rate (3%) which does not apply to operations with revenues of less than 12 million RwF annually (Jenkins, et al., 2016). Operations with a capacity of 100 birds are unable to generate the taxable revenue threshold of 12 million RwF given the prices used in this analysis.

The financial model was modified to reflect the agreement entered by the smallholders with the feed mill regarding the salary payments to technicians beginning in the fourth production cycle (Zamura Feeds, 2017). A grace period for unskilled labor was added to the finial model as:

$$UnSal_t = UnSal_{Monthly} \cdot 12 \cdot CPI_t \cdot \theta_t \quad (35)$$

where $UnSal_t$ is the salary of the unskilled worker in period (year) *t*, the constant 12 is the number of months in the year, and θ_t is the percentage of cycles in year *t* that the smallholder is responsible for paying the technician. The percentage of cycles is determined as:

$$\theta_t = \frac{\varphi_t}{Cyc_{Year}} \quad (36)$$

where φ_t is the number of cycles for which the smallholder must pay the technician in year *t*. Payable cycles is calculated as:

$$\varphi_t = Cyc_{Year}, \text{ if } \theta_{t-1} > \frac{\text{Grace}_{Unsal}}{Cyc_{Year}}, \text{and}$$

$$\varphi_t = Cyc_{Year} - Grace_{UnSal} + \theta_{t-1} \cdot Cyc_{Year}, \text{ if } \theta_{t-1} \leq \frac{\text{Grace}_{Unsal}}{Cyc_{Year}} \quad (37)$$

where $Grace_{UnSal}$ is the grace period in number of cycles before the smallholder is responsible for paying the technician, and θ_{t-1} is assumed to be zero in period t=1.

5.2 Simulation

The stochastic price of broiler feed was simulated using a PERT distribution which is generated using the maximum, minimum, and most likely values as parameters (Clemen and Reilly, 2001). The parameters used for the PERT distribution of feed price are the prices received by the feed mill (Nshuti, 2018).

Price indices calculated via equation 11 were made stochastic through the use of the random variable, $\gamma \sim N(0,1)$. The indices are calculated once for each iteration and are used for all scenarios with stochastic inflation.

All other stochastic variables in the financial model were bootstrapped from their observed distributions collected from the Musanze smallholder operations dataset because the availability of observed data eliminates the necessity to make assumptions about the distributions of the variables. The variables $Feed_{Cycle}$, $Mort_{Real}$, and β_{Sold} are endogenous because $Feed_{Cycle}$ is a function of β_{Sold} (equation 21), which is in turn a function of $Mort_{Real}$ (equation 24). To maintain the relationship of these variables during the simulation, the three variables sampled from the same observation. (For example, the data points for $Feed_{Cycle}$, $Mort_{Real}$, and β_{Sold} for iteration 23 were all drawn from observation 95; then for iteration 24, they were each drawn from observation 4, and so on) The values for these variables in each iteration was drawn from the random observation selected for that iteration.

The simulations were performed using @RISK© software (Palisade, 2010). The simulation was conducted using 5,000 iterations to provide a large enough number of outcomes

to reasonably expect that variation of the system has been accounted for without unnecessarily increasing computing time (Dušan Đ, et al., 2012). A fixed seed of 1 was used for all scenarios so that the random sampling process used by the software is the same for all inputs and can be used for future simulations.

5.3 Calibration

During each iteration, the financial indicators were recalculated, conditional on the stochastic outcomes of the random variables. Summary statistics calculated, and risk analyses were conducted for each scenario based on their respective distributions. The simulation models were calibrated to verify if the static, initial values of the models corresponded with production and return data collected by the feed mill. First, outlier observations were identified as being those where:

$$Mort_{Real} \geq 20\% \tag{38}$$

There were 12 of the 125 observations meeting this criterion. Average values for each stochastic variable were calculated for all variables using the 113 remaining observations. These average values were used to calibrate the stochastic variables for the observed data. The $RealNCF_{BefFint}$ in time period, t=1 (the first year of the production cycles) was compared to the average profit (π_{Avg}) of the 113 records to gauge how closely the simulation model replicated the observed data on smallholder broiler operation returns, and to identify which variables caused differences in return calculations. The prices used in the model are the prices gathered in the first year of production; therefore, the first-year average profit was used for the calibration comparison to use a value that does not depend on assumptions made about future price behavior. Because the financial model calculates $Real\ NCF_{BefFint}$ by year and data collected from the Musanze broiler

operations is recorded by production cycle, average profits from the Musanze data was compared to:

$$Calib = \frac{RealNCF_{BefFin_{t=2}}}{Cycle_{Year}} \tag{39}$$

where *Calib* is the profit per cycle calculated by the calibrated financial model. The variable *Calib* was used as the measure to compare to average profits because neither measure included the financing disbursements, investment costs, or loan payments.

Average profits calculated from the data were also converted to real terms by:

$$Real\pi_{Avg} = \frac{\pi_{Avg}}{CPI_{t=2}} \tag{40}$$

to make $Real\pi_{Avg}$ in terms of 2016 money commensurable with *Calib* since that is the base year of the financial model. The deterministic values for CPI_t from the Jenkins et al. (2016) were used in the calibrated financial model to eliminate variation among prices during the calibration process.

5.4 Scenarios

Each scenario was conducted independently, but each stochastic variable in the scenarios was calculated using the same set of randomly drawn variables. This strategy ensured that the scenarios are comparable to each other, and to the baseline. Therefore, each scenario was calculated identically for each iteration except for the value or calculation that differentiated that scenario from the baseline scenario. A complete list of scenarios with descriptions follows (Table 3). The scenarios were conducted independently rather than simultaneously to show the effects each strategy change had on NPV and MIRR.

The first scenario (S0) is the financial model using the deterministic values for the price index (CPI_t) constructed by Jenkins et al. (2016). This scenario was used as a reference to compare with the stochastic financial models (e.g. stochastic CPI_t based on Brownian motion).

A baseline scenario was created using the stochastic variable *Infl* (equation 10). Each scenario that follows is identical to the baseline scenario except for the decision variable being changed to simulate the effects of different production strategies. The following scenarios were compared to the baseline scenario rather than being compared to S0 because the baseline and all following scenarios have stochastic inflation. The CPI values for each time period are the same across all but the S0 scenario for each iteration, so the only difference being observed when comparing scenarios S1 though S5 to the baseline scenario is the change in production strategy specific to that scenario whereas, comparing S1 through S5 to S0 would require accounting for the difference resulting from stochastic rather than deterministic inflation also.

Scenario S1 incorporates bird mortality ($Mort_{Assm}$). Unlike $Mort_{Real}$, which is a stochastic mortality rate observed when broilers don't survive the first two weeks of the production cycle, $Mort_{Assm}$ is the mortality rate the producer assumes might occur. In anticipation of some loss of chicks, when the producer assumes an a priori mortality rate, they may purchase additional chicks to compensate for expected losses (Eq. 25). Scenario S1 includes an assumed mortality rate of $Mort_{Assm}$ = 5%. This mortality rate was used because it is the mode of the observed chick mortality data. Therefore, if the producer plans to produce 100 broilers (β_p =100), and assumes there will be 5% mortality ($Mort_{Assm}$ = .05), that producer would purchase 105 DOCs expecting that when 5 DOCs die, they would still have 100 broilers to produce. When $Mort_{Assm}$ is increased to 5%, returns are expected to increase due additional revenue from selling the additional birds.

Scenario S2 represents an increased grace period before the producer assumes the burden of paying technician salaries of 11,000 RwF per month. Rather than the 3-cycle grace period described in the agreement between the program participants and the feed mill, S2 uses a grace period of 5 cycles (Zamura Feeds, 2017). Through a sensitivity analysis wherein the grace period was increased by one production cycle over five simulations of 500 iterations each, the mean NPV went from negative to positive when changing the grace period from 4 cycles to 5 (Table 4). Because increasing the grace period to 5 cycles results in positive mean NPV, that was the value chosen for scenario S2. The result of the sensitivity analysis is expected to carry through to the simulation resulting in an increase in NPV and MIRR as well as a decrease in DPB when the grace period for paying for technical services is increased from 3 production cycles to 5.

Scenarios S3 and S4 involve different ways to price broilers. Scenarios S0 through S2, and S5 all sample broiler prices (P_{Br}) from the 125 observations which include 64 observations where the P_{Br} was based on the price negotiated with the purchaser (min=1,152, median=1,347, max=2,219 RwF/Kg). The P_{Br} values in the remaining 61 observations were set at a flat rate by the feed mill (contract price), received by all producers who were selling their flocks at the same time (min=1,323, median=1,360, max=1,432 RwF/Kg). Those 61 observations are made up of 3 groups of producers who received contract pricing for their broilers. The 13 producers in group 1 received 1,323 RwF/Kg for their broilers, the 12 producers in group 2 received 1,432 RwF/Kg for their broilers, and the 36 producers in group 3 received 1,360 RwF/Kg for their broilers. The P_{Br} in S3 was only sampled from the 64 market price observations, and P_{Br} in S4 was only sampled from the 61 contract price observations. Due to the greater range of prices in the market price group (S3), standard deviation is expected to be higher than that of the baseline or the contract price group (S4). Effects on mean NPV, MIRR, and DPB are uncertain.

Scenario (S5) includes revenues from the sale of manure produced by the operations. Manure revenues were included in the model by changing the value of $Prod_{Man}$ from zero to 5 40 Kg bags, an amount stated by Nshuti (2018), and P_{Man} from zero to a random draw from the PERT distribution with parameters (in RwF/bag) of min=719, most likely=1,562, max=3,199 (Lambert, et al., 2017). Because the sale of manure creates additional revenue for the operation, NPV and MIRR are expected to increase while DPB is expected to decrease with little if any effect on standard deviation of NPV and MIRR.

The stochastic dominance spreadsheet model developed by Lambert and Lowenberg-DeBoer (2003) was used to evaluate first and second degree stochastic dominance among scenarios. Simulated NPV and MIRR data were used in the model. Because MIRR functions did not converge for approximately 0.1% of the iterations, scenario data used did not have the same number of observations. To correct for this, truncated (-100%) MIRR values were removed from the data and the remaining data was used to calculate percentiles (%) which resulted in equal observations (n=99) of MIRR data.

CHAPTER VI: RESULTS

After calibrating the financial model, *Calib* was calculated to be 51,797 RwF ± 21,268. Compared to $Real\pi_{Avg}$ of 53,982 RwF ± 21,268, amounting to a difference of $Real\pi_{Avg}$ of 4.05%, a difference of las than 5% margin of error. Additionally, the difference of 2,185 RwF is 10.27% of the standard deviation in $Real\pi_{Avg}$ (Table 5). These discrepancies are negligible and suggest that the simulation models are calibrated within an acceptable margin of error.

The deterministic inflation simulation, S0, resulted in an expected NPV of -84.568 ± 1,902,489 (mean ± standard deviation) RwF and expected MIRR of -18.15 ± 26.31% (Table 6). The stochastic inflation simulation, baseline, resulted in an expected NPV of -81,062 ± 1,899,360 RwF and expected MIRR of -18.14 ± 56.32% (Table 6). The CDFs for S0 and baseline are not visually distinguishable for the NPVs or MIRRs (Figures 6 and 7). The chance of loss, mean DPB, and probability of DPB being 5 years or less are all equal for the S0 and baseline scenarios (49.8%, 8.87 years, and 56.3% respectively) (Table 6). There is not a large change in the result when using stochastic inflation to forecast prices compared to using deterministic inflation.

Table 7 reports the summary statistics for the NPVs and MIRRs resulting from the baseline scenario and S1 which includes $Mort_{Assm}$ to simulate the decision to purchase additional DOCs as a safeguard against $Mort_{Real}$. Compared to the NPV results for the baseline, S1 resulted in a higher expected NPV and standard deviation (314,057 ± 1,979,277 RwF), which means that the MV criteria is inconclusive for determining the risk efficiency of the baseline and S1 with NPVs. The SD analysis of the baseline and S1 using their respective NPVs determined that S1 dominated the baseline by FDSD. Visual inspection of the CDFs shows that the distribution for

S1 lies below and to the right of the baseline distribution of NPVs and has a chance of loss of 41.7% compared to the chance of loss for the baseline scenario of 49.8% for an 8.1% decrease in chance of loss when assuming 5% mortality compared to not assuming mortality (Table 7). The mean DPB dropped from 8.87 years to 7.50 years when assuming 5% mortality and the probability of DPB being 5 years or less increased from 56.3% to 63.3% (Table 7). The spreadsheet model also determined that S1 NPVs dominate the baseline NPVs because the area below S1's distribution was calculated to be less than the area below the baseline distribution, and no intersections of the CDFs were found (Table 8). The KS test indicates that the null hypothesis that the distributions for the NPVs calculated from the baseline and S1 are equal to one another should be rejected (D-stat=0.0980, p-value= 0.000) (Table 9).

The MIRR comparison of these two scenarios (baseline and S1) by the MV and SD criterion each result in a preference for S1. Scenario S1 has higher mean and lower standard deviation of MIRR (-9.55 ± 53.20%). In other words, S1 is more risk efficient than the baseline according to the MV criteria. Scenario S1 is also the dominant strategy over the baseline by FDSD because there is less area below the CDF for MIRRs calculated by S1 than below the CDF for MIRRs calculated by the baseline and the two CDFs do not intersect (other than for MIRRs truncated at -1.00) (Figure 9). The stochastic dominance model also determined that the MIRR distribution of S1 is FDSD dominant over the MIRR distribution of the baseline (Table 8). The KS test indicates that the null hypothesis that the distributions for the MIRRs calculated from the baseline and S1 are equal to one another should be rejected (D-stat=0.0980, p-value= 0.000) (Table 9).

The effects of extending the grace period before the smallholder broiler producers are responsible for paying for technical support from three production cycles to five is simulated in

S2. The NPVs calculated by S2 had a higher mean and the same standard deviation (-41,205 ± 1,899,360 RwF) as those calculated by the baseline (-81,062 ± 1,899,360 RwF) (Table 10). The chance of loss with S2 was 49.0% which is 0.8% lower than the chance of loss from the baseline scenario (Table 10). The mean DPB dropped from 8.87 years to 8.71 years when increasing the grace period to pay for technical services, and the probability of DPB being 5 years or less increased from 56.3% to 57.6% (Table 10). The MV criterion is inconclusive when comparing these two scenarios by their NPVs. Stochastic dominance of NPV distributions of S2 and the baseline cannot be determined visually in this instance (Figure 10). However, the stochastic dominance model determined that S2 dominates the baseline strategy by FDSD. The KS test fails to reject the null that the distributions of NPVs for the baseline and S2 scenarios are equal (D-stat=0.0124, p-value=0.837) (Table 9).

Risk efficiency of S2 and the baseline scenario cannot be determined using the MIRR and the MV criteria because the expected MIRR and standard deviation are both higher for S2 than for the baseline scenario (-17.99% ± 56.41%) (Table 10). MIRR for S2 compared to the baseline had the same result as the NPV distributions of the same scenario comparison. The distributions are visually indistinguishable, the stochastic dominance spreadsheet model found S2 to be FDSD over the baseline, and the KS test failed to reject the null that the MIRR distribution of S2 is equal to that of the baseline (D-stat=0.0126, p-value=0.822) (Figure 11, Table9, Table 10).

Scenarios 3 and 4 are compared to the baseline because they are different strategies for pricing broilers. The CDFs of the NPVs for the baseline, S3, and S4 scenarios are too close to provide information about which ones may be preferable (Figure 12). However, the chance of loss increased from the baseline value of 49.8% to 51.7% chance of loss when simulating S3, but with S4 the chance of loss decreased from the 49.8% baseline value to 48.2% (Table 11). The

mean DPB for S3 was 9.08 and was 8.66 for S4 and the probability of DPB being 5 years or less for S3 and S4 was 54.6% and 57.3%, respectively (Table 11). Comparing NPV distributions of the scenarios, scenario S3 has the highest mean, but also the highest standard deviation (-48,293 ± 2,076,874 RwF); therefore, S3 cannot be efficient compared to the other two scenarios, nor can the baseline or S4 be efficient compared to S3 when compared by NPVs. Scenario S4 has the lowest mean and standard deviation (-111,192 ± 1,735,022 RwF), and because the mean and standard deviation for the baseline lies between the values for S3 and S4, there is no efficient set when being compared by NPVs with the MV criterion (Table 11). Figures 13, 14, and 15 rank stochastic inputs in order of those which have the most impact on average NPV to the least. These three figures show that when broilers are sold only at market price, the broiler price is the 2nd most impactful stochastic input while broiler price is the 4th most impactful stochastic input affecting mean NPV when broilers are only sold at a contracted price (Figures 13, 14, and 15). The stochastic dominance spreadsheet model, which only compares two distributions at one time, was used to compare the NPV distributions of the baseline to S3, the baseline to S4, and S3 to S4. All three comparisons were inconclusive (Table 8). The KS test on the NPV distributions of the baseline compared to S3 failed to reject the null (with D=0.0198, p-val=0.281). The KS test rejected the null that the NPV distribution for the baseline is equal to the NPV distribution of S4, and that the NPV distribution for S3 is equal to the NPV distribution of S4 (D-stat=0.0332, p-val=0.008, and D-stat=0.0456, p-val=0.000, respectively) (Table9).

Table 11 shows that, for the MIRR values, scenario S4 has a higher mean and lower standard deviation (-16.33% ± 55.31%) than S3 (-18.14% ± 56.32%) and the baseline (-18.85% ± 56.55%) (Table 11). Therefore, S4 is risk efficient compared to S3 and the baseline by MV criteria. Figure 16 shows the CDFs of the MIRRs of these three scenarios (Figure 16). The

spreadsheet model for SD did not determine any stochastic dominance among the baseline, S3, and S4 scenarios (Table 8). The KS test failed to reject the null that the distributions of MIRRs were equal for the baseline compared with S3 (D-stat=0.0198, p-value=0.281). However, the KS test rejected the null that the NPV distribution for the baseline is equal to the NPV distribution of S4, and that the NPV distribution for S3 is equal to the NPV distribution of S4 (D-stat=0.0332, p-val=0.008, and D-stat=0.0456, p-val=0.000, respectively) (Table9).

Scenario S5 simulates the financial performance of the broiler operations if producers were to bag and sell poultry manure. The NPV distribution for S5 appears to dominate the distribution of the baseline NPVs by FDSD because the two distributions do not appear to cross, and the distribution for S5 lies below and to the right of the distribution for the baseline NPVs (Figure 17). The chance of loss from S5 of 381% is 11.7% lower than the 49.8% chance of loss from the baseline scenario (Table 12). The mean DPB dropped from 8.87 years to 6.78 years when assuming 5% mortality and the probability of DPB being 5 years or less increased from 56.3% to 67.3% (Table 12). The NPV distribution for S5 has a higher mean and standard deviation than that of the baseline (S5: 490,048 ± 1,904,872 RwF) (baseline: -81,062 ± 1,899,360 RwF), therefore, neither scenario is risk efficient compared to the other when compared by NPVs. The stochastic dominance model determined that S5 is dominant over the baseline by FDSD when compared by NPVs (Table 8). The KS test rejected the null that the NPV distributions for S5 and the baseline scenario are equal (D-stat=0.1314, p-value=0.000) (Table 9).

Scenario S5 is risk efficient compared to the baseline by the MV criteria as measured with the MIRRs (-5.35% ± 50.95%) (Table 12). Scenario S5 also appears to dominate the baseline by FDSD because the area below the CDF of MIRRs calculated with S5 is smaller than

the area below the CDF of MIRRs calculated with the baseline, and the CDFs do not intersect (Figure 18). The same was found using the stochastic dominance model. When compared by MIRRs, S5 dominates the baseline by FDSD (Table 8). The KS test rejected the null that the MIRR distributions for S5 and the baseline scenario are equal (D-stat=0.1314, p-value=0.000) (Table 9).

CHAPTER VII: CONCLUSION

This research aims to provide smallholder broiler producers in Musanze, Rwanda with information to help increase the efficiency of their operations by providing a financial risk analysis that estimates net present values and modified internal rates of return for different smallholder broiler production technology combinations using stochastic forecasts of inflation rates while accounting for the variability in costs of production, market prices, and production uncertainty. The financial risk analysis model found that the current structure of the TI project operates on a small profit margin with a nearly 49.8% chance of not recovering investment costs. However, this analysis found that by selling the manure produced by the operation, the chance of loss can be reduced by 11.7% to 38.1%, and mean NPV can go from negative to positive (Table 12). The analysis also found that significant gains can be made from purchasing 5 extra DOCs to compensate for mortality of chicks. Other strategies tested showed improvement but were not as definitive.

The sale of manure creates an additional revenue stream for smallholders that provides the most improvement across all measures recorded in this analysis compared to the other strategies assessed and should be the first change implemented by smallholder broiler producers. This is consistent with the expectation that manure sales would improve revenues without much effect on variance. There was no cost for labor to collect the manure or bags included in this model. Those costs would reduce the benefit of that additional revenue stream to the producer, so these results may be inflated. Assuming that the price received by the producer is sufficient to cover any production cost of the manure, financial returns to the operation would increase

without increasing to variance leading to a dominant strategy. As shown by Table 13, this strategy was found to be dominant for all but MV criteria assessed by NPV.

Assuming 5% mortality and purchasing additional DOCs to safeguard against that chance of loss is more risk efficient than only purchasing the number of birds the producer plans to sell at the end of the cycle by all criteria measured with the exception of MV criteria assessed by NPV. This was consistent with the expectation that having more broilers to sell would increase revenues. Purchasing extra DOCs should be the second strategy change implemented by producers as it resulted in the second highest improvement across all measures recorded in this analysis.

The extension of the grace period before the producers are responsible for paying for technical assistance by two cycles (from 3 cycles to 5) improved outcomes slightly, but the CDFs were not found to be statistically different by the KS test and there was no conclusion found by the MV criteria. While the positive change in NPV and MIRR was expected, the small magnitude of impact was surprising. The small magnitude is an example of how viewing the present value of 20 years of returns puts two cycles of technical service pay into perspective. This strategy was found to be FDSD over the baseline (Table 13). This strategy would likely be an improvement, though the small magnitude of that improvement as well as the fact that the investment lender would need to agree to assume payment for technical services for the additional two cycles means that this strategy would require more than a decision by the producer and would not be justified by the small potential gains expected from the change.

There are not overwhelming results indicating one dominant broiler pricing strategy. While the contract price (S4) was found to be efficient compared to market price (S3) and a mix of contract and market price (baseline) when compared by MIRR, the mean NPV was much

lower for the contract price strategy. The reduced DPB and increased chance of loss were not expected results of S3 and are results of low-end variation outweighing the high-end variation of only selling broilers at market price. No change in broiler pricing strategy is recommended as a result of this analysis, and producers should continue to sell some portion of their broilers at contract price to guard against low-end variation and sell some portion at market price to have potential to enjoy prices resulting from high-end variation.

These strategies are not mutually exclusive. An ideal strategy could be assembled using the efficient set found in this research. To achieve the risk optimal strategy from the scenarios evaluated here, a producer could sell the manure produced by their operation and purchase additional DOCs to safeguard against chick mortality. The DPBs for the scenarios raged from 6.78 years for S5 to 9.08 years for S3 indicating that on average, with the ideal strategy, a smallholder may recover their investment within 10 years, but would likely not within 5 years.

The MV criteria identified efficient strategies for five scenarios when comparing MIRR distributions while no efficient strategies were identified when comparing NPV distributions of the same scenarios (Table 13). There were also negative mean MIRRs when positive mean NPVs were recorded (Tables 7 and 12). This discrepancy is due to the MIRR function resulting in a -100% when no positive net returns occur over the planning horizon. This skews the distribution making the mean value for the MIRRs lower than what it should be. For those iterations where the MIRR result was -100%, the NPV was negative, but finite. In future research, different treatment of MIRR data should be examined.

The MIRR cannot take on a value less than 100% because it is based on investment costs. The measure assumes that an investment cannot lose more than is invested in it. Because the NPV does not have a minimum possible value, the iterations with the worst financial

performance result in worse outcomes measured by NPV than can be accounted for with MIRR. Therefore, scenarios compared with MIRRs will typically appear more favorable than those compared with NPVs, particularly when there is more downside risk involved.

It is important to note that the data was collected from the first 3 flocks produced by the producers which raises two issues to consider regarding the effects of experience on output. First, one would expect more efficient production to occur with a producer's third flock compared to their first which leads to some variation among the observations. The second issue is that over the 20-year planning horizon, producers are expected to produce 5 flocks per year, totaling 100 flocks. Similar to the first issue, one would expect a producer with the experience of producing almost 100 flocks to be much more efficient and have higher profits than one who has only produced 3 flocks. Therefore, the results produced by this research are likely conservative considering the reasonable expectation that the producers will likely improve their level of efficiency as they produce additional flocks.

Further research should be conducted to take into account the risk preferences of the smallholder broiler producers via stochastic efficiency with respect to a function (SERF) analysis. Another improvement on current information would be to obtain poultry industry data for other regions in Rwanda and use that data to make changes to this model to identify optimal production strategies under different circumstances. Future research should also focus on other parts of the poultry sector, including markets for inputs such as feed and heating sources. Demand levels, potential for future demand, and public preferences for poultry products should also be examined.

This research provides information about the effects of production strategies available to smallholder broiler producers in rural Rwanda through the use of observed and estimated data

using Monte Carlo simulation to simulate variability of costs of production, market prices and production uncertainty as well as simulating inflation rates to account for variability in future prices. If the smallholder broiler producers in Musanze are able to identify and adopt strategies that improve their financial outcomes of their operations, their broiler operations are more likely to succeed. The success of these operations can provide income for the producers and their families as well as nutrition for them and their communities. With additional income, they can stimulate their local economy creating demand for goods which can lead to jobs for others.

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APPENDIX

TABLES

Table 1. Poultry Producers Across Provinces of Rwanda

		Province					
		Central	Northern	Eastern	Western	Southern	Rwanda (Total)
Type	Layers (farm)	57%	84%	82%	75%	78%	72%
	Broilers (farm)	43%	16%	18%	35%	22%	28%
	Layers (bird)	79%	99%	86%	66%	82%	92%
	Broilers (bird)	21%	1%	14%	34%	18%	8%
Totals	Layers (birds)	38495	112227	47730	9563	4795	212810
	Broilers (birds)	10300	300	4100	2075	1680	18455
	Feed demand (layers) (ton)	74	343	94	23	14	550
	Feed demand (broilers) (ton)	24	9	2	6	3	46
	Monthly feed demand (ton)	99	352	97	29	17	596
Median birds per house (birds)		666	290	367	561	173	666

Source: Leding and Miller (2013)

Table 2. Variables Used in Baseline Financial Risk Analysis Model

Category	Variable	Units	Min	Mean	Max
Scale	Capacity of the farm	birds		100	
	Capacity utilization	%		100	
	Production cycle	days		63	
	Number of cycles	cycles		6	
	Annual broiler production capacity	birds		600	
Investment	Initial investment cost	RwF		527,861	
	Land requirement	Ha		0	
	Price of land	RwF/Ha		198,412	
	Buildings	RwF		485,261	
	Equipment	RwF		42,600	
	Adult feeder	RwF		21,600	
	Chick feed plates	RwF		10,000	
	Drinkers	RwF		7,600	
	Clay Pots	RwF		3,400	
	Electricity and water installation	RwF		0	
Labor	Number of unskilled labor	#	0	1	1
	Salary of unskilled labor	RwF/Month	0	5,238	5,238
	Number of skilled labor	#		0	
	Salary of skilled labor	RwF/Month		100,000	
Operating	Vaccines†	RwF/bird	2	5.17	8
	Slaughtering and Packaging service per cycle	RwF/bird		0	
	Charcoal†	RwF/Month	4,285	12,960	15,714
	Water†	RwF/Month	1,428	1,546	1,667
	General maintenance cost			0	
	Bedding†	RwF/Month	0	1,447	2,476
	Disinfectant †	RwF/Month		714	

Note: † Stochastic variable

Mean, min, and max are calculated from observed data in RwF/cycle and converted into RwF/month as:

$Cost\ per\ month = \left[Cost\ per\ cycle \cdot \left(30/Cycle_{Days}\right)\right]$

$Mean = 1/n \sum_{i=1}^{n} x$

Min is the smallest value in the set.

Max is the largest value in the set.

Source: Jenkins et al. (2016), International Programs (2017)

Table 2. Variables Used in Baseline Financial Risk Analysis Model, continued

Category	Variable	Units	Min	Mean	Max
Production	Average feeding per cycle	Kg/bird	2.13	5.68	8.97
	Average carcass weight †	Kg/bird	1.10	2.68	3.30
	Manure production (in full operating capacity)	Packs/month		0	
	Realized Mortality rate of DOCs (first two weeks) †	%	0.00%	8.20%	39.00%
	Assumed Mortality rate of DOCs (first two weeks)	%	0.00%	5.00%	20.00%
	Broilers sold at farm gate †	birds	61	91.8	100
	Poultry mix feed †	RwF/Kg	310	350	380
	Manure	RwF/Pack		0	
	DOCs (Broilers)	RwF/bird		680	
	Broilers at farm gate †	RwF/Kg	1151.52	1370.83	2219.37
Macro Information	Discount rate	%		17%	
	Reinvestment rate/Economic opportunity cost of capital (EOCK)	%		17%	
	Real exchange rate	RwF/USD		840	
Macroeconomic Indicators	US price index (1967-2016)	index	-0.3555	4.1192	13.5094
	Rwanda price index (1967-2016)	index	-2.4059	7.6111	31.0883
	US inflation rate (est. 2016-2036) †	%	1.15%	2.28%	2.38%
	Rwanda inflation rate (est. 2016-2036) †	%	4.25%	4.96%	5.00%

† Stochastic variables

Source: Jenkins et al. (2016), International Programs (2017)

Table 3. Scenarios Compared in the Risk Analysis of Smallholder Broiler Operations

Scenario	Name	Alteration from Baseline
S0†	Deterministic Inflation	Deterministic values for future CPI's
Baseline	Stochastic Inflation (Baseline)	None
S1	Assumed Mortality	Assume 5% Mortality
S2	Delayed Technician Payment	Increase grace period to pay a technician from 3 cycles to 5 cycles
S3	Market Price (of Broilers)	Sample broiler price from producers who sold at market price
S4	Contract Price (of Broilers)	Sample broiler price from producers who sold at a flat rate offered to sellers in a production cycle
S5	Sell Manure	Producers sell manure produced by the broiler operation

Note: † based on Jenkins et al. (2016) CPI.

Table 4. Sensitivity Analysis of Grace Period for Producer Payment for Technical Services Effect on Mean Net Present Value (NPV) over 500 Iterations

Grace Period (Cycles)	Mean NPV (RwF)
3	-194,782
4	-104,017
5	93,181
6	187,991
7	200,746

Table 5. Comparison of Average Profits from Musanze Operations and Real Net Cashflows Before Financing from Calibrated Financial Model

	RwF/Cycle	USD/Cycle
Average profit (reference)	53,982	64.26
Real NCF (calibrated)	51,797	61.66
Difference	-2,185	-2.60
Standard dev.	21,268	25.32
Diff. as portion of avg profit	-4.05%	
Diff. as portion of std. dev.	-10.27%	

Table 6. Summary Statistics of Deterministic Inflation and Stochastic Inflation (baseline) Scenarios (S0 and Baseline, respectively)

	NPV (RwF)		MIRR	
	S0	Baseline	S0	Baseline
Min	-7,354,166	-7,340,133	-100.00%	-100.00%
Mean	-84,568	-81,062	-18.15%	-18.14%
Max	8,124,284	8,131,321	34.56%	34.57%
5% Lower Bound	-3,191,899	-3,187,040	-100.00%	-100.00%
95% Upper Bound	2,823,666	2,832,339	28.33%	28.34%
Std Dev	1,902,489	1,899,360	56.31%	56.32%
	S0		Baseline	
Chance of Loss	49.8%		49.8%	
Mean DPB (years)	8.87		8.87	
Prob. DPB ≤ 5 years	56.3%		56.3%	

Note: Chance of loss is the probability that the Net Present Value (NPV) is negative
DPB is Discounted payback period measured in years

Table 7. Summary Statistics of Stochastic Inflation (baseline) and Assumed Mortality (S1) Scenarios

	NPV (RwF)		MIRR	
	Baseline	Assumed Mort.	Baseline	Assumed Mort.
Min	-7,340,133	-7,256,623	-100.00%	-100.00%
Mean	-81,062	314,057	-18.14%	-9.55%
Max	8,131,321	8,955,230	34.57%	35.18%
5% Lower Bound	-3,187,040	-2,928,942	-100.00%	-100.00%
95% Upper Bound	2,832,339	3,331,810	28.34%	29.24%
Std Dev	1,899,360	1,979,277	56.32%	53.20%
	Baseline		Assumed Mort	
Chance of Loss	49.8%		41.7%	
Mean DPB (years)	8.87		7.50	
Prob. DPB ≤ 5 years	56.3%		63.3%	

Note: Chance of loss is the probability that the Net Present Value (NPV) is negative
DPB is Discounted payback period measured in years

Table 8. Results of Stochastic Dominance Analysis of Production Scenarios for Smallholder Broiler Producers in Musanze, Rwanda (Baseline, S1, S2, S3, S4, and S5)

	NPV		MIRR	
	Dominant Scenario	Degree	Dominant Scenario	Degree
Base v S1	S1	FDSD	S1	FDSD
Base v S2	S2	FDSD	S2	FDSD
Base v S3	-	-	-	-
Base v S4	-	-	-	-
S3 v S4	-	-	-	-
Base v S5	S5	FDSD	S5	FDSD

Note: First Degree Stochastic Dominant (FDSD)
Second Degree Stochastic Dominant (SDSD)
Inconclusive (-)

Table 9. Results of Kolmogorov-Smirnov (KS) Tests for Distribution Equality Between Scenarios

	NPV		MIRR	
Comparison	D	P-value	D	P-value
Base vs. S1	0.0980	0.000***	0.0980	0.000***
Base vs. S2	0.0124	0.837	0.0126	0.822
Base vs. S3	0.0198	0.281	0.0198	0.281
Base vs. S4	0.0332	0.008***	0.0332	0.008***
S3 vs. S4	0.0456	0.000***	0.0456	0.000***
Base vs. S5	0.1314	0.000***	0.1314	0.000***

Note: * 10% significance level

** 5% significance level

*** 1% significance level

Table 10. Summary Statistics of Stochastic Inflation (baseline) and Delayed Technician Payment (S2) Scenarios

	NPV (RwF)		MIRR	
	Baseline	Incr. Salary Grace	Baseline	Incr. Salary Grace
Min	-7,340,133	-7,300,277	-100.00%	-100.00%
Mean	-81,062	-41,205	-18.14%	-17.99%
Max	8,131,321	8,171,178	34.57%	34.60%
5% Lower Bound	-3,187,040	-3,147,183	-100.00%	-100.00%
95% Upper Bound	2,832,339	2,872,196	28.34%	28.42%
Std Dev	1,899,360	1,899,360	56.32%	56.41%
	Baseline		Incr. Salary Grace	
Chance of Loss	49.8%		49.0%	
Mean DPB (years)	8.87		8.71	
Prob. DPB ≤ 5 years	56.3%		57.6%	

Note: Chance of loss is the probability that the Net Present Value (NPV) is negative
DPB is Discounted payback period measured in years

Table 11. Summary Statistics of Stochastic Inflation (baseline), Market Price of Broilers (S3) and Contract Price of Broilers (S4) Scenarios

	NPV (RwF)			MIRR		
	Baseline	Mkt Price	Contract Price	Baseline	Mkt Price	Contract Price
Min	-7,340,133	-7,416,141	-6,956,317	-100.00%	-100.00%	-100.00%
Mean	-81,062	-48,293	-111,192	-18.14%	-18.85%	-16.33%
Max	8,131,321	10,410,339	4,577,860	34.57%	36.15%	31.06%
5% Lower Bound	-3,187,040	-3,259,131	-3,026,215	-100.00%	-100.00%	-100.00%
95% Upper Bound	2,832,339	3,170,404	2,512,740	28.30%	28.96%	27.70%
Std Dev	1,899,360	2,076,874	1,735,022	56.32%	56.55%	55.31%

	Baseline	Mkt Price	Contract Price
Chance of Loss	49.8%	51.5%	48.2%
Mean DPB (years)	8.87	9.08	8.66
Prob. DPB ≤ 5 years	56.3%	54.6%	57.3%

Note: Chance of loss is the probability that the Net Present Value (NPV) is negative
DPB is Discounted payback period measured in years

Table 12. Summary Statistics of Stochastic Inflation (baseline) and Sell Manure Scenarios (S5)

	NPV (RwF)		MIRR	
	Baseline	Sell Manure	Baseline	Sell Manure
Min	-7,340,133	-6,754,150	-100.00%	-100.00%
Mean	-81,062	490,042	-18.14%	-5.35%
Max	8,131,321	8,950,013	34.57%	35.17%
5% Lower Bound	-3,187,040	-2,649,154	-100.00%	-100.00%
95% Upper Bound	2,832,339	3,389,708	28.30%	29.33%
Std Dev	1,899,360	1,904,872	56.32%	50.95%

	Baseline	Sell Manure
Chance of Loss	49.8%	38.1%
Mean DPB (years)	8.87	6.78
Prob. DPB ≤ 5 years	56.3%	67.3%

Note: Chance of loss is the probability that the Net Present Value (NPV) is negative
DPB is Discounted payback period measured in years

Table 13. Summary of Results from Risk Analyses of Production Scenarios for Smallholder Broiler Producers

	S1 v B	S2 v B	S3 v B	S4 v B	B v S3	B v S4	S3 v S4	S4 v S3	S5 v B
MV									
NPV	-	-	-	-	-	-	-	-	-
MIRR	EF	-	-	EF	EF	-	-	EF	EF
SD									
NPV	FDSD	FDSD	-	-	-	-	-	-	FDSD
MIRR	FDSD	FDSD	-	-	-	-	-	-	FDSD
KS									
NPV	Reject	-	-	Reject	-	Reject	Reject	Reject	Reject
MIRR	Reject	-	-	Reject	-	Reject	Reject	Reject	Reject

Note: Baseline (B)
Mean-variance criteria (MV)
First degree stochastic dominance (FDSD)
Second degree dtochastic dominance (SDSD)
Stochastic dominance criteria (SD)
Risk Efficient (EF)
Kolmogorov-Smirnov test (KS)
Reject the null hypothesis that the distributions are statistically equal (Reject)
Results are for the first scenario listed compared to the second (e.g. S1 v B = FD means that scenario 1 is first degree stochastic dominant over the baseline.

FIGURES

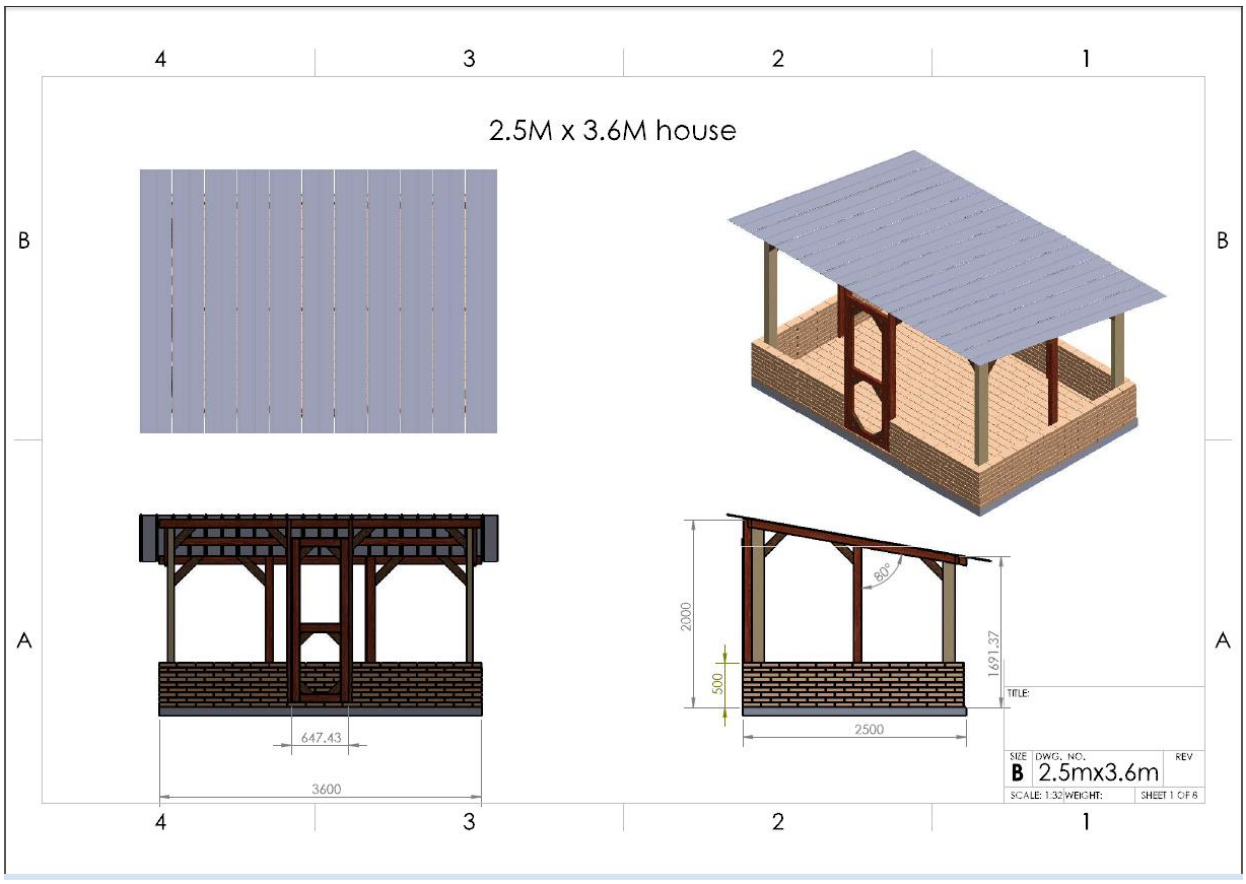

Figure 1. Coop design for Smallholder Broiler Producers in Musanze Rwanda

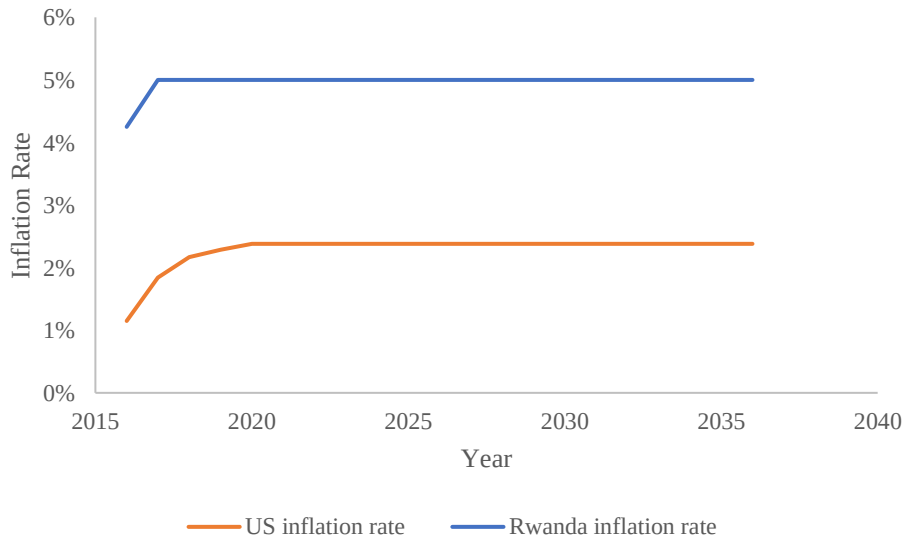

Figure 2. Forecasted Inflation Rates for Rwanda and The United States 2016-2036 (Jenkins, et al., 2016)

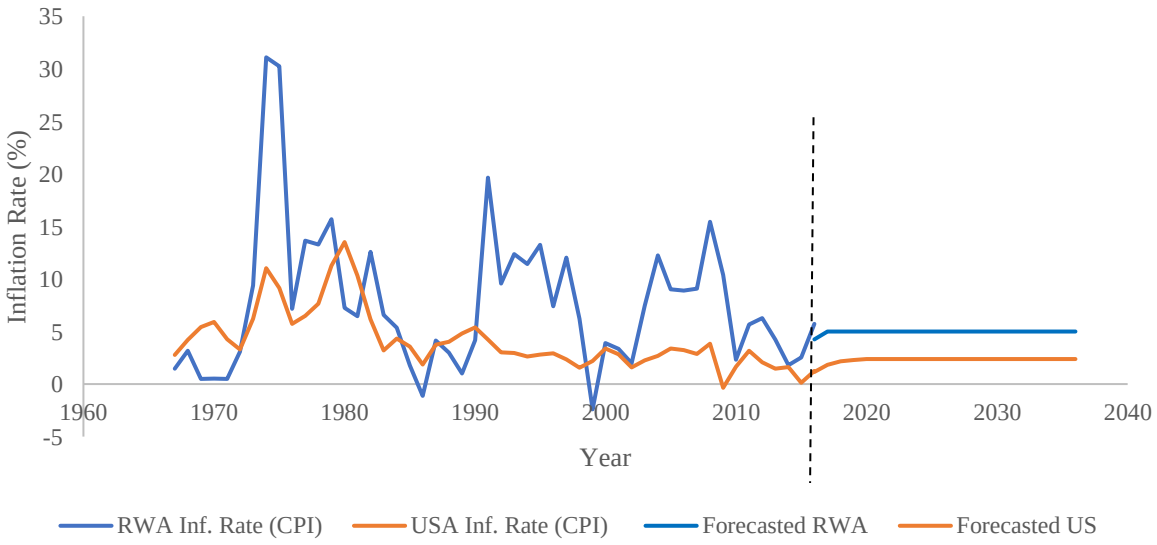

Figure 3. Recorded CPI Inflation Rates for Rwanda and the Unites States 1967-2016 and Inflation Rates Forecasted for 2016-2036 by Jenkins et al. (2016) (Worldbank, 2017)

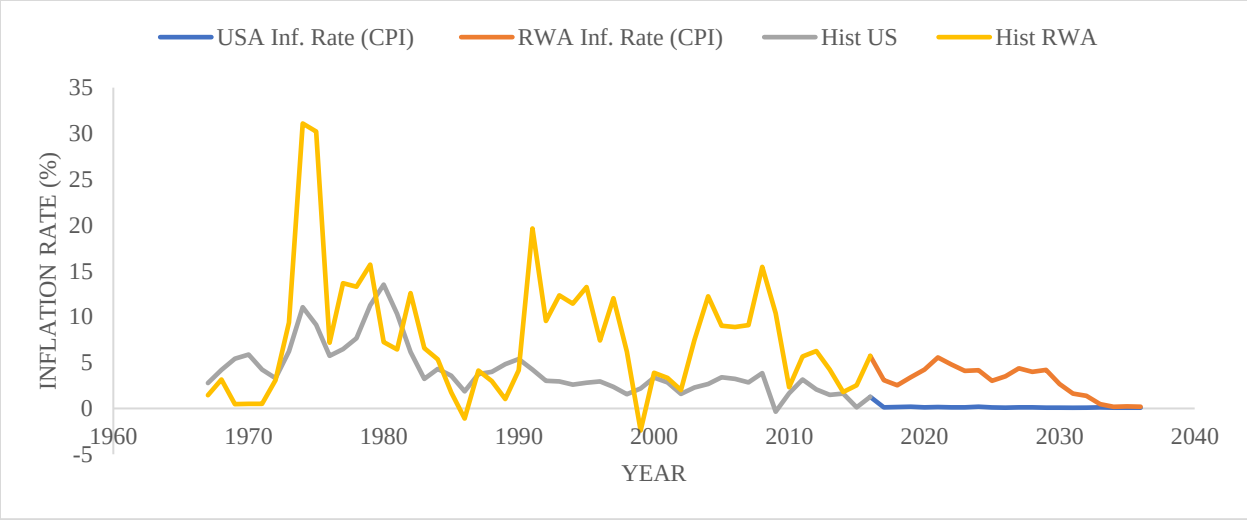

Figure 4. Historic Price Indices for Rwanda and United States 1967-2016 and Simulated 2017-2036 with Brownian Motion (Worldbank, 2017)

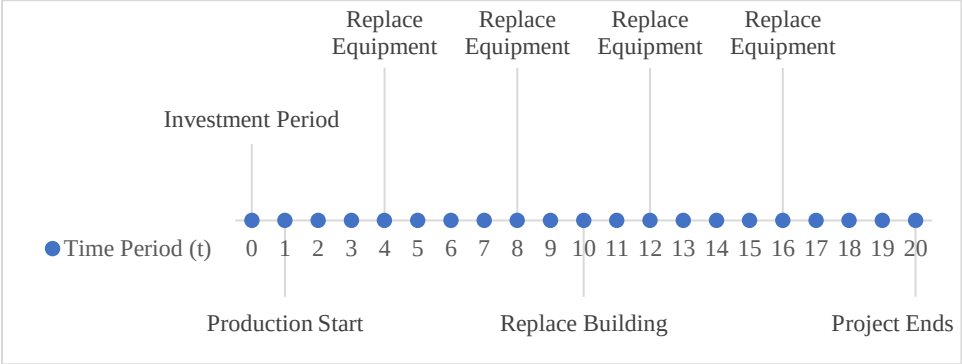

Figure 5. Timeline of Planning Horizon for Smallholder Poultry Financial Model

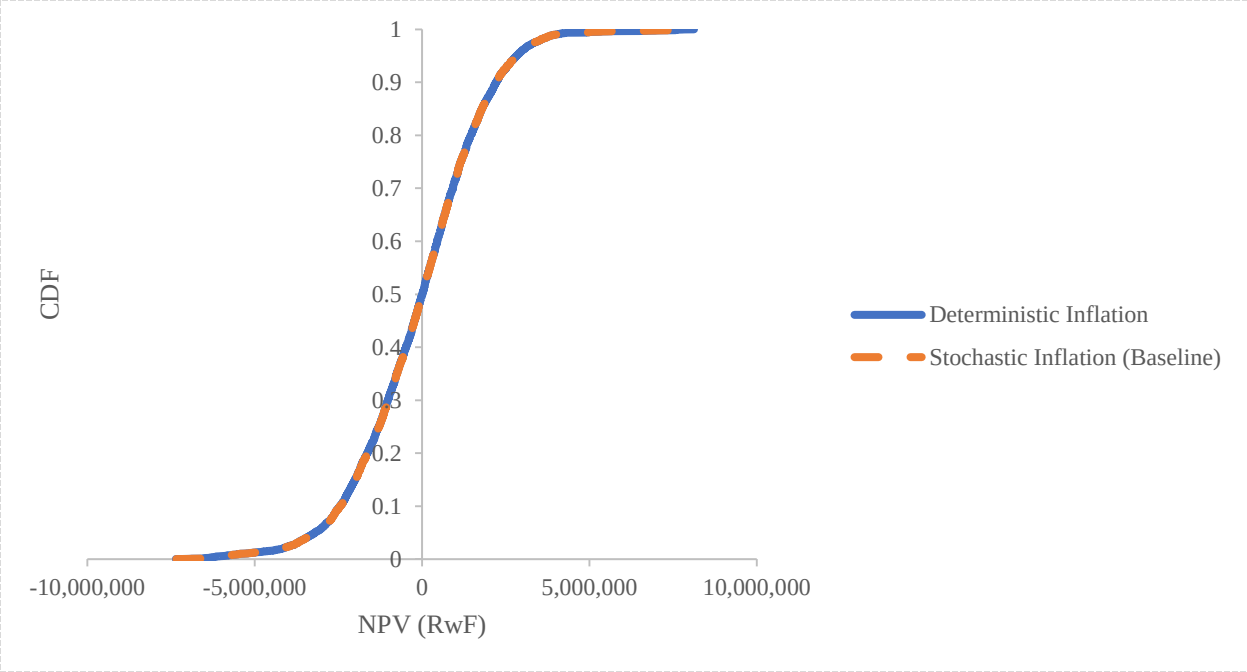

Figure 6. CDF of NPVs from Simulation of Deterministic Inflation (S0) and Stochastic Inflation (Baseline)

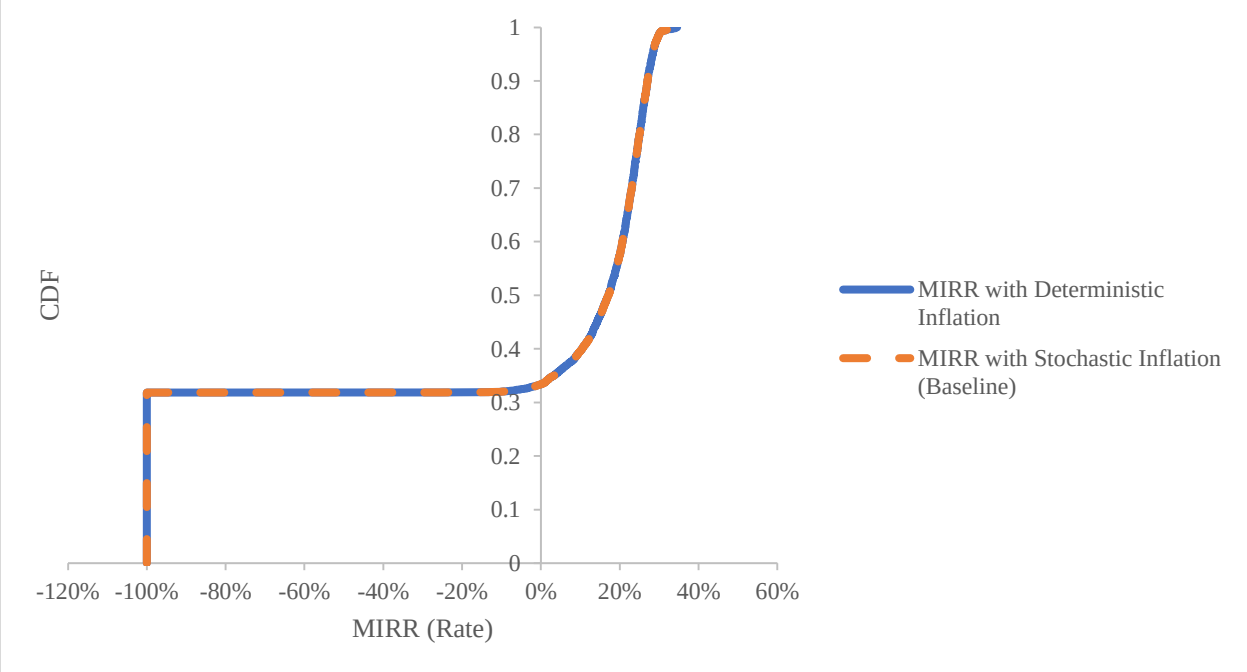

Figure 7. CDF of MIRRs from Simulation of Deterministic Inflation (S0) and Stochastic Inflation (Baseline)

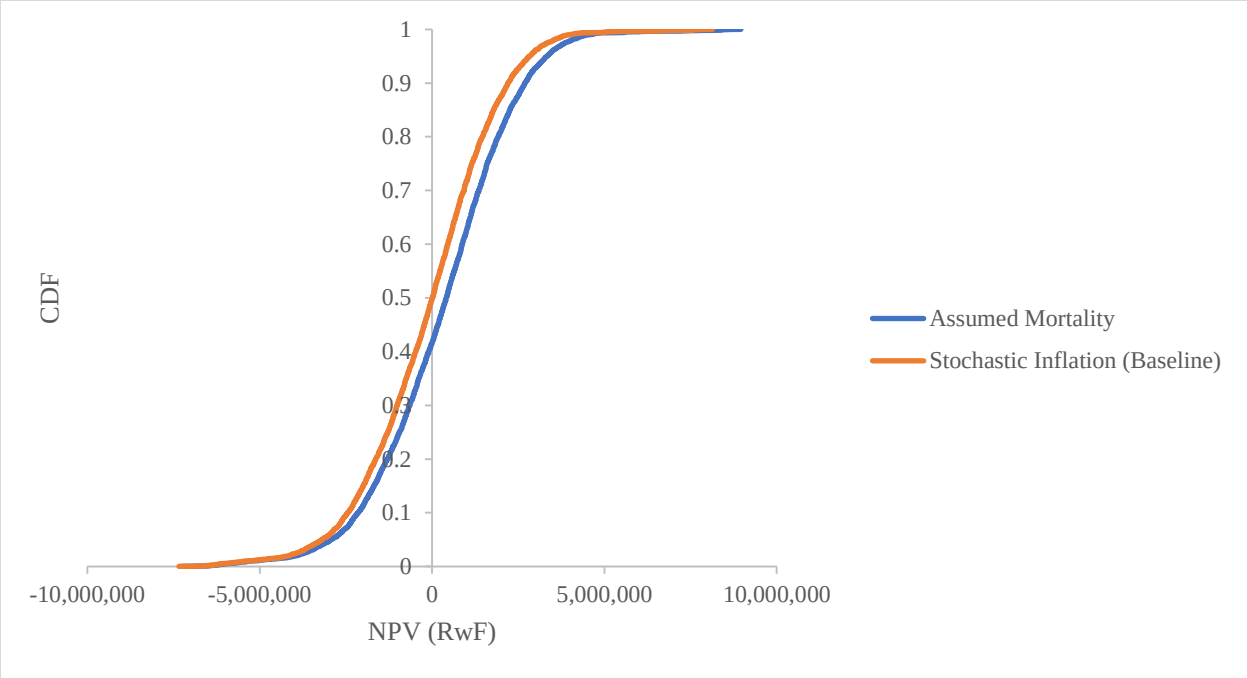

Figure 8. CDF of NPVs from Simulation of Stochastic Inflation (Baseline) and Assumed Mortality (S1)

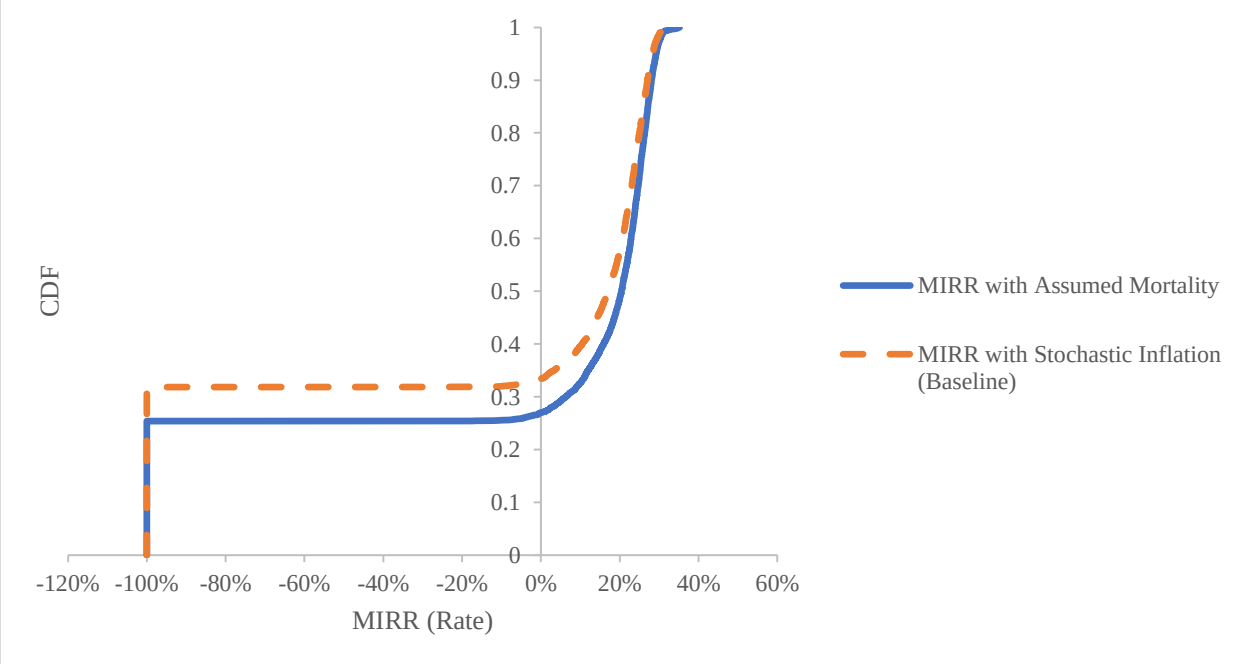

Figure 9. CDF of MIRRs from Simulation of Stochastic Inflation (Baseline) and Assumed Mortality (S1)

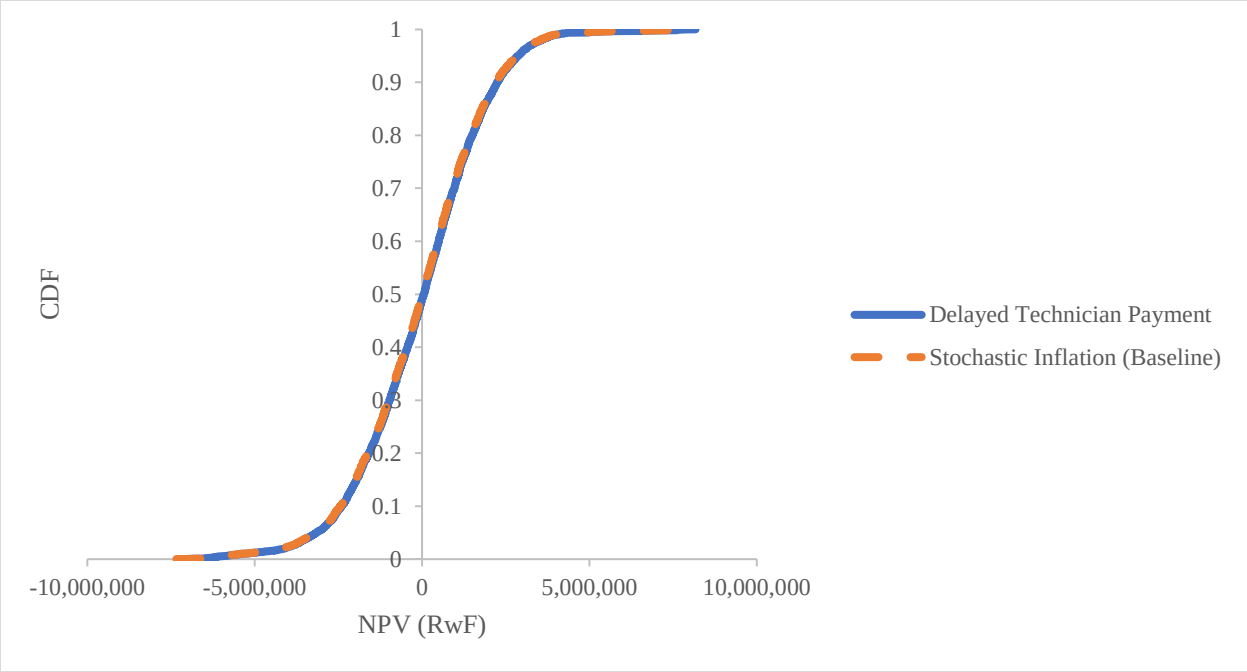

Figure 10. CDF of NPVs from Simulation of Stochastic Inflation (Baseline) and Delayed Technician Pay (S2)

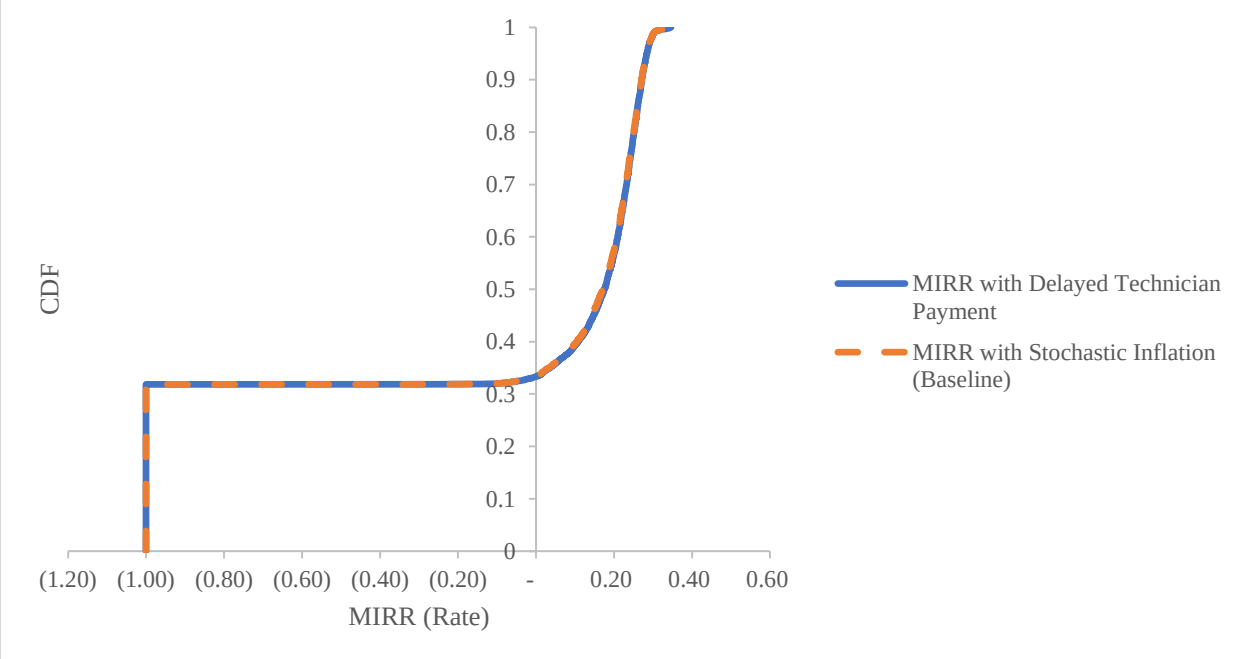

Figure 11. CDF of MIRRs from Simulation of Stochastic Inflation (Baseline) and Delayed Technician Pay (S2)

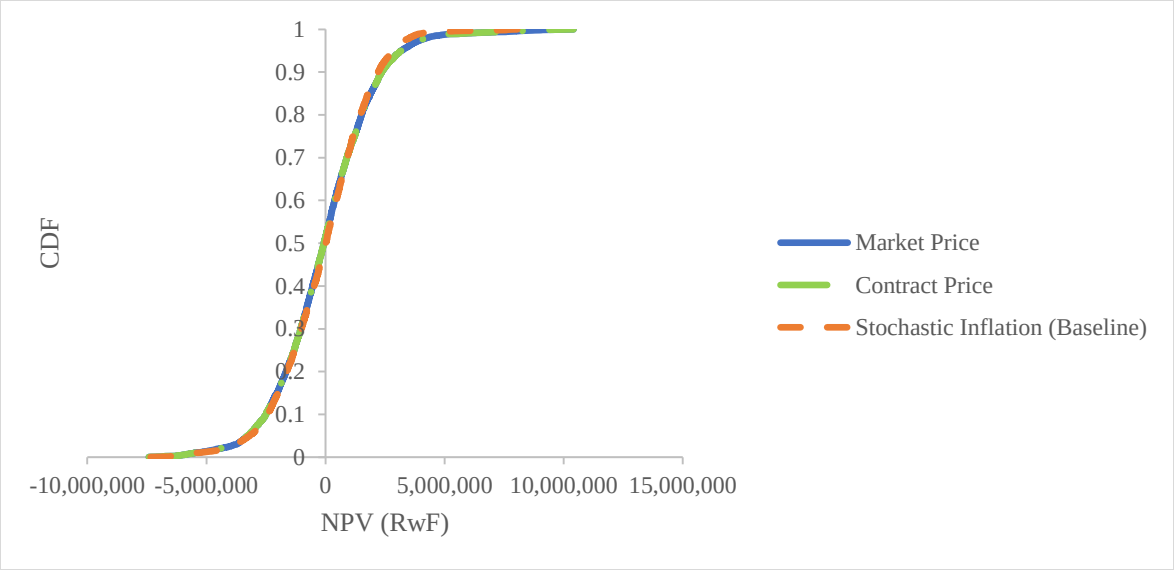

Figure 12. CDF of NPVs from Simulation of Stochastic Inflation (Baseline), Market Price (of Broilers) (S3) and Contract Price (of Broilers) (S4)

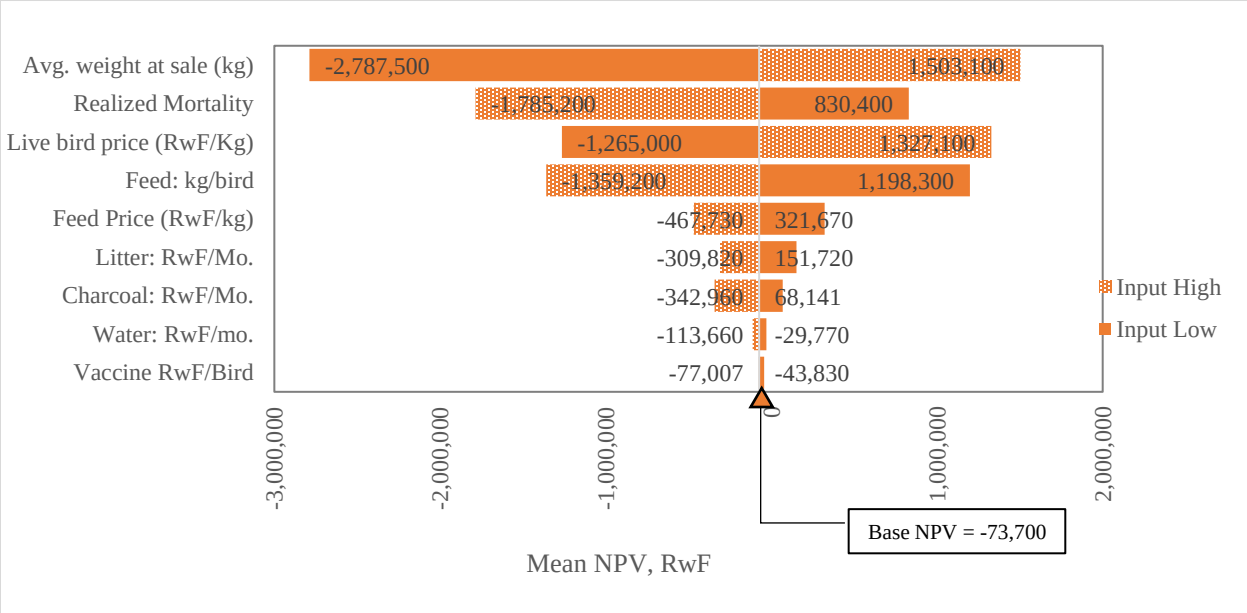

Figure13. Inputs Ranked by Effect on Mean Net Present Value (NPV) Resulting from the Baseline Simulation

Note: Values on the left of the bar are the mean NPV when the lowest value of the stochastic input is used while values on the right of the bar are the mean NPV when the highest value of the stochastic input is used.

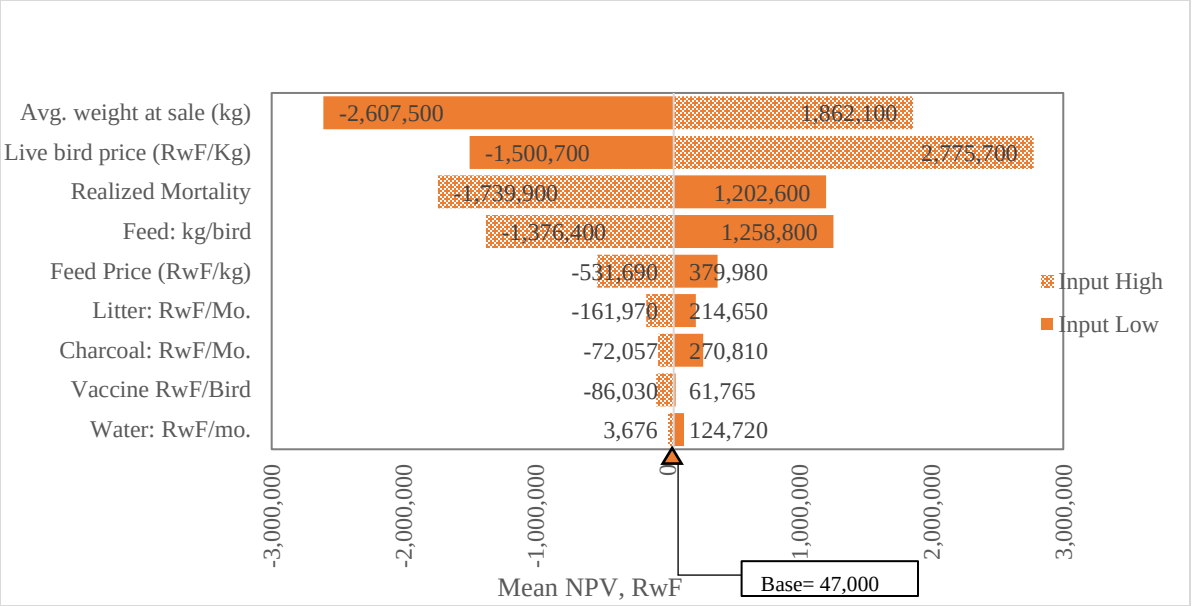

Figure14. Inputs Ranked by Effect on Mean Net Present Value (NPV) Resulting from the Market Price (S3) Simulation

Note: Values on the left of the bar are the mean NPV when the lowest value of the stochastic input is used while values on the right of the bar are the mean NPV when the highest value of the stochastic input is used.

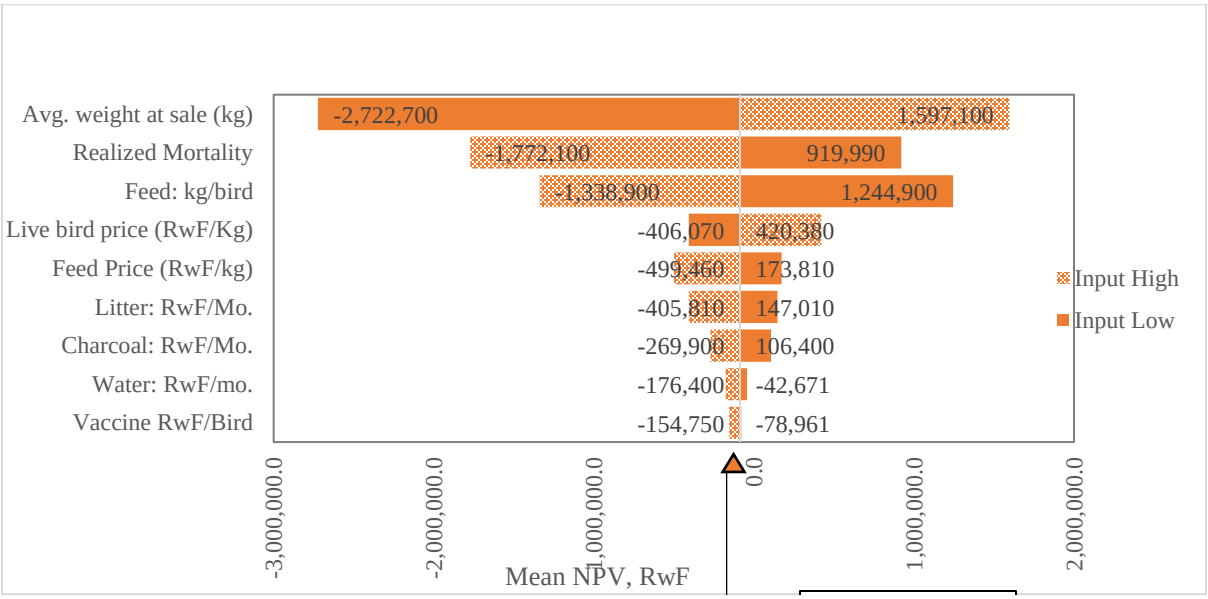

Figure15. Inputs Ranked by Effect on Mean Net Present Value (NPV) Resulting from the Contract Price (S4) Simulation

Note: Values on the left of the bar are the mean NPV when the lowest value of the stochastic input is used while values on the right of the bar are the mean NPV when the highest value of the stochastic input is used.

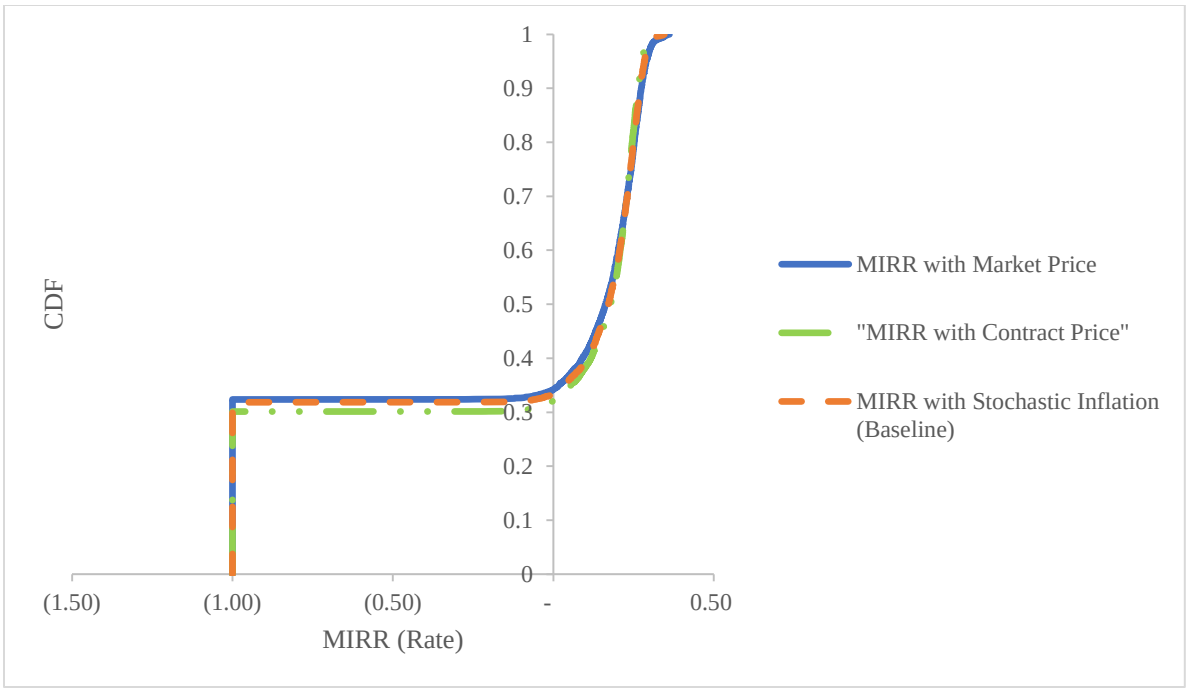

Figure 16. CDF of MIRRs from Simulation of Stochastic Inflation (Baseline), Market Price (of Broilers) (S3) and Contract Price (of Broilers) (S4)

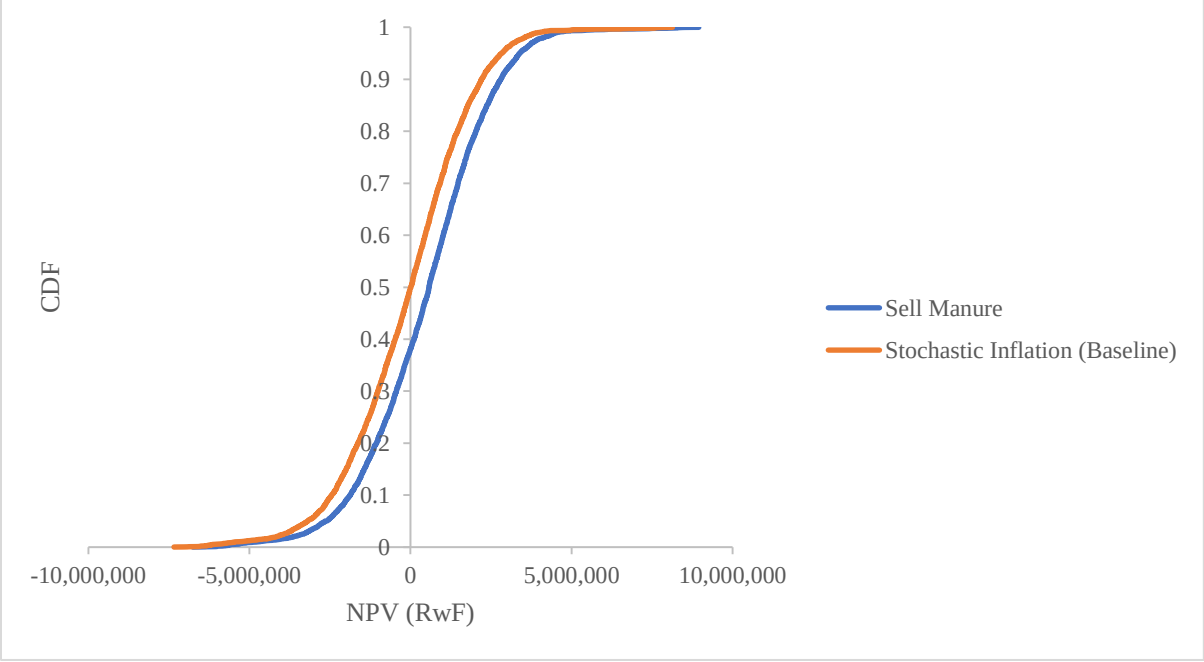

Figure 17. CDF of NPVs from Simulation of Stochastic Inflation (Baseline) and Sell Manure (S5)

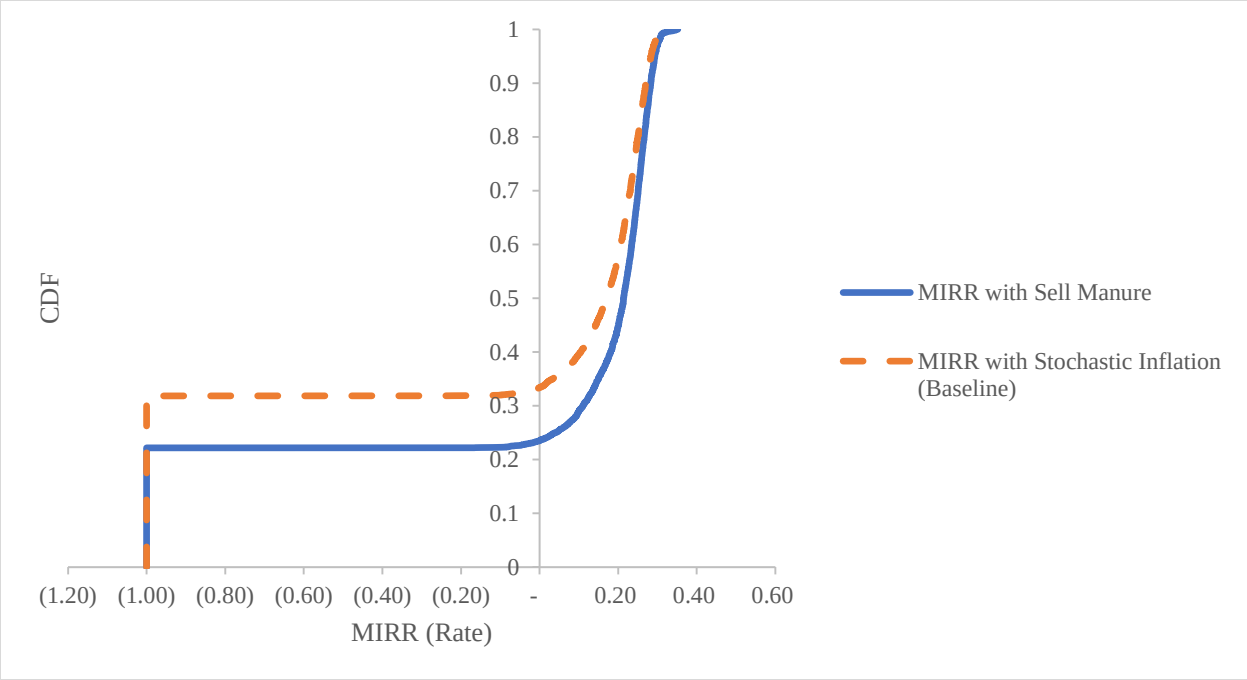

Figure 18. CDF of MIRRs from Simulation of Stochastic Inflation (Baseline) and Sell Manure (S5)

VITA

Bartholomew (Bart) Wade Kenner was born in Florissant, Missouri to Pamela and Gary Kenner. After moving around quite a bit, Bart and Pamela settled in Crossville, Tennessee from 1995 through 2002 when Bart moved to Knoxville, Tennessee to attend the University of Tennessee where he obtained a Bachelor of Arts in Economics. While pursuing his bachelor's degree, Bart became the Regional Asset Manager of the family business, Kenner Investment Group, working alongside Gary. After graduation, Bart worked as a self-employed Property Manager for six years before returning to the University of Tennessee for a Master of Science degree in Agricultural Economics with a minor in Statistics. He graduated in December of 2018.