ECONOMICS OF THE AGRICULTURAL AVIATION INDUSTRY IN THE UNITED STATES: DETERMINATION OF OPTIMUM PROFIT UNDER VARYING AIRCRAFT AND RISK

A Thesis

by

STEPHEN HARTMAN CAIN

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	Senarath Dharmasena
Committee Members,	David A. Bessler
	David J. Leatham
Head of Department,	Mark L. Waller

August 2019

Major Subject: Agricultural Economics

ABSTRACT

In this thesis, we develop a stochastic simulation model with risk that simulates pricing and costs for the purpose of deriving profit per acre for a U.S. aerial applicator. Given the high startup and maintenance cost associated with the competitive aerial application industry, we look at price and cost associated with targeted profit margins and the probability of meeting those profit margins. We evaluate the empirical distribution of prices and costs for spray jobs and determine the optimum profit per acre for three different types of commonly used aircraft which are identified by hopper size; small, medium and large. This study is conducted without full cost data and therefore the conclusions drawn offer a picture into what is possible with full data. With the information available, we rank the most profitable spray application by aircraft, based on predetermined risk aversion coefficients. Across all profit margins, the small hopper (SH) aircraft is preferred by the risk averse operators while the large hopper (LH) aircraft is preferred by the risk loving operators and the medium hopper (MH) aircraft preference is in between the SH and LH.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Senarath Dharmasena, and my committee members, Dr. Bessler and Dr. Leatham, for their guidance and support throughout the course of this research. I would also like to thank Dr. Daniel Martin for his assistance and insight. I would like to thank the aerial applicator who generously provided the data necessary for this study. Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. Finally, thanks to my family for their encouragement and to my uncle for his support and generosity.

CONTRIBUTORS AND FUNDING SOURCES

This work was supervised by a thesis committee consisting of Professors Senarath Dharmasena, David Bessler and David Leatham of the Department of Agricultural Economics and special help from Daniel Martin of the USDA's Agricultural Research Service.

The cost and revenue data, that without which this study would not have been possible, was generously provided by an agricultural aerial applicator located in the Upper Midwest.

All work for the thesis was completed by the student, under the advisement of Senarath Dharmasena of the Department of Agricultural Economics and Daniel Martin of the USDA's Agricultural Research Service.

There are no outside funding contributions to acknowledge related to the research and compilation of this document.

NOMENCLATURE

Π	Profit
ARAC	Absolute Risk Aversion Coefficient
C	Cost
CDF	Cumulative Distribution Function
CE	Certainty Equivalent
EMP	Empirical
LH	Large Hopper Aircraft
MH	Medium Hopper Aircraft
NAAA	National Agricultural Aviation Association
PDF	Probability Density Function
R	Revenue
RAC	Risk Aversion Coefficient
SDRF	Stochastic Dominance with Respect to a Function
SERF	Stochastic Efficiency with Respect to a Function
SH	Small Hopper Aircraft
StDev	Standard Deviation

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

1. INTRODUCTION AND LITERATURE REVIEW

Aerial applications (application of liquid and dry materials via air) have been used in the United States for nearly one hundred years for producing a safe, affordable and abundant supply of food, fiber and biofuel, in addition to protecting forestry and controlling health-threatening pests (NAAA, 2016). According to the National Agricultural Aviation Association (NAAA) of the United States, aerial application is a very critical component of high-yielding and highly efficient current-day U.S. agriculture. Compared to ground application equipment (ground rigs), aerial application is up to three times as efficient and can treat a variety of fields such as those that are significantly wet, compacted, prone to topsoil runoff, and have thick crop canopy (such as orchards). The agricultural aviation industry treats 71 million acres of cropland each year, which is about 25% of the total commercially treated cropland in the United States (NAAA, 2016).

Aerial applicators are individuals who are highly trained and have made significant investments in their business due to the high-tech nature of the modern-day agricultural aviation industry in the United States (NAAA, 2016). Today's agricultural aircraft use high-tech precision application equipment such as Global Positioning Systems, geographical information systems, flow controls, aerial imaging systems and real-time meteorological systems along with precisely calibrated spraying equipment (NAAA, 2016). On average, agricultural aircraft could cost between $100,000 to $1.4 million, depending on the size and type of aircraft and related accessories. Other cost items include fuel, repairs and maintenance, insurance, costs associated with regulations imposed by government regulatory bodies, pilot and ground crew pay, housing, meals, etc., making this an expensive enterprise to operate as well as to maintain. Variations in aircraft fuel prices and equipment costs (such as booms, nozzles, spreaders, navigation systems, flow controllers, etc.) could adversely impact the intended revenue and profit margins of the operators. Moreover, risk associated with accidental drift of chemicals and subsequent damage to near-by agricultural crops could add extra cost that the application business must deal with and for which must have insurance. Also, given the increasing competition from various aerial operations for spray jobs as well as the high cost of the operation, small differences in the price charged per acre (or hour) per job could make or break a business. Consequently, precision pricing is crucial for anyone in this business to achieve the desired level of revenue and profit, provided the unique costs and risks associated with aerial applications. Aforementioned questions are something that most of the aerial applicators struggle with in a fairly competitive application industry. With that being said, to the best of our knowledge, we could not find any scientific studies in the extant literature that directly address these questions with regards to the aerial application industry of the United States. The information resulting from this study will be useful for applicators in the aerial application industry to make strategic decisions with regards to pricing of the service (product) to make sufficient profit to remain viable in the industry, given the unique cost, revenue and risk structure. The general objective of this study is to develop a simulation model with risk that simulates costs and price for spray jobs while assessing the probability of meeting a desired profit margin. Specific objectives are to:

(1) evaluate the empirical distribution of prices and costs charged for spray jobs to assess probability of meeting different predetermined profit margins of 5%, 10%, 15% and 20% for three different types of commonly used aircraft which are identified by hopper size; small (SH), medium (MH) and large (LH);

(2) determine the profit per acre for spray jobs, given predetermined targeted profit margins of 5%, 10%, 15% and 20% for three different types of commonly used aircraft referred to in this study as SH, MH and LH; and

(3) rank the most profitable spray application by aircraft, based on predetermined risk aversion coefficients using cumulative distribution functions, stochastic dominance graphs and stop light graphs.

2. DATA AND METHODOLOGY

In this study, we develop a simulation model with risk that simulates price and costs for an aerial applicator of the United States. We determine at what pricing level generating a specific profit per acre an applicator would need to charge using a specific aircraft. A test study was conducted using data provided by an aerial applicator located in the upper Midwest of the United States. Revenue and cost information from this operator was collected, which in turn was used to simulate optimum revenue and profit per acre for the applicator. Revenue information is comprised of number of acres sprayed and price charged for each job. Cost information includes fixed costs such as insurance, maintenance, repairs and real estate (buildings, aircraft hangars, runways, etc.), and aircraft and variable costs (transitory costs) such as fuel, pilot pay, ground crew, employee meals and housing. A simple profit function is used where profit (Π) equals revenue (R) minus costs (C). The "x" represents the variables that determine revenue and costs discussed above.

$$\Pi = R(x) - C(x)$$

In these models, certain parameters were held constant to compare scenarios. A factor that impacts pricing is field shape. The more complex a field shape is, the more passes an aircraft will need to make in order the fully cover the field which adds flight time and fuel usage. A rectangle is the easiest, real world field shape on which to apply product. With this in mind, field shape was held constant at a rectangle shape in this study. Also, application was assumed to be constant at two gallons per acre of liquid product. Load time becomes more of a factor as the acreage increases requiring more trips back to base to load more product. Load time is the time required to reload the aircraft hopper with the product being applied as well as fuel. This is separate from tach time which is the time required to fly between the field and home base. Load time in this study is held constant across aircraft at 20 minutes. Turn time is the time taken in between passes on a field allowing the aircraft to turn around and resume spraying on the next pass. This is done in between every pass across the field. Turn time may vary with pilot skill level and terrain around the field. For this reason, turn time is held constant at 45 seconds in this study. Distance to base is a factor impacting tach time which is the time necessary to fly to and from the field to refill hoppers on the aircraft. This distance is held constant at five miles. Lastly, fuel is an important variable cost which impacts operations and is held constant at four dollars per gallon.

We look at three of the most popular aircraft used in the industry and four target profit margins. The aircraft examined are identified by the hopper size of small (referred to in this study as SH), medium (referred to in this study as MH) and large (referred to in this study as LH). Profit margins for a typical aerial applicator are between five and twenty percent with most operating somewhere in the middle. To account for varying profit margins, in this study, we examined four profit margins at 5%, 10%, 15% and 20%. Twelve scenarios were run analyzing each aircraft at each desired profit margin. Using the cost and revenue data provided by the aerial applicator, profit is held at a constant level to determine optimum pricing levels at varying rectangular field sizes. Field sizes start at 50 acres and increase to 2,000 acres at increments of 50.

Pricing is extracted and an empirical distribution is generated with 40 observations using the actual data. This pricing data was extracted from the model used by the aerial applicator out of the Upper Midwest. This allows us to use real world pricing that is currently seen in the market place. Each table below shows a short summary of each scenario with summary statistics on profit per acre.

Table 2.1 Scenario 1 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**SH**	Field Shape:	Rectangle	Mean:	$0.28
Profit Margin:	**5%**	Application:	2 gal/ac Liquid Product	StDev:	0.02473
		Load Time:	20 Minutes	Min:	$0.27
		Turn Time:	45 Seconds	Median:	$0.27
		Distance to Base:	5 Miles	Max:	$0.38
		Fuel Price:	$4/gal		

Table 2.2 Scenario 2 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**MH**	Field Shape:	Rectangle	Mean:	$0.45
Profit Margin:	**5%**	Application:	2 gal/ac Liquid Product	StDev:	0.18070
		Load Time:	20 Minutes	Min:	$0.34
		Turn Time:	45 Seconds	Median:	$0.39
		Distance to Base:	5 Miles	Max:	$1.36
		Fuel Price:	$4/gal		

Table 2.3 Scenario 3 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**LH**	Field Shape:	Rectangle	Mean:	$0.44
Profit Margin:	**5%**	Application:	2 gal/ac Liquid Product	StDev:	0.22259
		Load Time:	20 Minutes	Min:	$0.32
		Turn Time:	45 Seconds	Median:	$0.37
		Distance to Base:	5 Miles	Max:	$1.57
		Fuel Price:	$4/gal		

Table 2.4 Scenario 4 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**SH**	Field Shape:	Rectangle	Mean:	$0.56
Profit Margin:	**10%**	Application:	2 gal/ac Liquid Product	StDev:	0.04945
		Load Time:	20 Minutes	Min:	$0.54
		Turn Time:	45 Seconds	Median:	$0.55
		Distance to Base:	5 Miles	Max:	$0.76
		Fuel Price:	$4/gal		

Table 2.5 Scenario 5 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**MH**	Field Shape:	Rectangle	Mean:	$0.89
Profit Margin:	**10%**	Application:	2 gal/ac Liquid Product	StDev:	0.36139
		Load Time:	20 Minutes	Min:	$0.67
		Turn Time:	45 Seconds	Median:	$0.78
		Distance to Base:	5 Miles	Max:	$2.72
		Fuel Price:	$4/gal		

Table 2.6 Scenario 6 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**LH**	Field Shape:	Rectangle	Mean:	$0.89
Profit Margin:	**10%**	Application:	2 gal/ac Liquid Product	StDev:	0.44518
		Load Time:	20 Minutes	Min:	$0.63
		Turn Time:	45 Seconds	Median:	$0.74
		Distance to Base:	5 Miles	Max:	$3.15
		Fuel Price:	$4/gal		

Table 2.7 Scenario 7 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**SH**	Field Shape:	Rectangle	Mean:	$0.84
Profit Margin:	**15%**	Application:	2 gal/ac Liquid Product	StDev:	0.07419
		Load Time:	20 Minutes	Min:	$0.80
		Turn Time:	45 Seconds	Median:	$0.82
		Distance to Base:	5 Miles	Max:	$1.14
		Fuel Price:	$4/gal		

Table 2.8 Scenario 8 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**MH**	Field Shape:	Rectangle	Mean:	$1.34
Profit Margin:	**15%**	Application:	2 gal/ac Liquid Product	StDev:	0.54202
		Load Time:	20 Minutes	Min:	$1.01
		Turn Time:	45 Seconds	Median:	$1.16
		Distance to Base:	5 Miles	Max:	$4.09
		Fuel Price:	$4/gal		

Table 2.9 Scenario 9 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**LH**	Field Shape:	Rectangle	Mean:	$1.33
Profit Margin:	**15%**	Application:	2 gal/ac Liquid Product	StDev:	0.66772
		Load Time:	20 Minutes	Min:	$0.95
		Turn Time:	45 Seconds	Median:	$1.11
		Distance to Base:	5 Miles	Max:	$4.72
		Fuel Price:	$4/gal		

Table 2.10 Scenario 10 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**SH**	Field Shape:	Rectangle	Mean:	$1.12
Profit Margin:	**20%**	Application:	2 gal/ac Liquid Product	StDev:	0.09891
		Load Time:	20 Minutes	Min:	$1.07
		Turn Time:	45 Seconds	Median:	$1.09
		Distance to Base:	5 Miles	Max:	$1.52
		Fuel Price:	$4/gal		

Table 2.11 Scenario 11 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**MH**	Field Shape:	Rectangle	Mean:	$1.79
Profit Margin:	**20%**	Application:	2 gal/ac Liquid Product	StDev:	0.72278
		Load Time:	20 Minutes	Min:	$1.34
		Turn Time:	45 Seconds	Median:	$1.55
		Distance to Base:	5 Miles	Max:	$5.45
		Fuel Price:	$4/gal		

Table 2.12 Scenario 12 Summary

VARIABLES		CONSTANTS		SUMMARY STATISTICS	
Aircraft:	**LH**	Field Shape:	Rectangle	Mean:	$1.77
Profit Margin:	**20%**	Application:	2 gal/ac Liquid Product	StDev:	0.89037
		Load Time:	20 Minutes	Min:	$1.27
		Turn Time:	45 Seconds	Median:	$1.48
		Distance to Base:	5 Miles	Max:	$6.30
		Fuel Price:	$4/gal		

An empirical distribution of price per acre and cost per acre, each was used to let the data define the shape of the distribution and not force an assumed distribution shape. This is done for each aircraft at each profit margin. This empirical distribution of profit per acre is then simulated for 500 iterations using the Latin Hypercube simulation (Greene, 2003) procedure available within SIMETAR statistical software (Richardson et al., 2008) and applied as in Dharmasena et al., (2014). Probability density functions (PDFs) and cumulative distribution functions (CDFs) for profit per acre are then generated, showing the stochastic nature of these variables. The CDFs developed for different aircraft types across different profit margins were compared to find the most profitable aircraft for each scenario.

Next, Stochastic Dominance with Respect to a Function (SDRF) and Stochastic Efficiency with Respect to a Function (SERF) tests were run across a series of risk aversion coefficients, which are available through SIMETAR, in order to compare the scenarios. The SDRF test was used to see which scenario was most preferred between varying risk averse coefficients. This tests also creates a graphical representation of allowing a visual aid to make the decision as to which aircraft is most profitable.

SERF tests were run in order to rank scenarios by which maximizes certainty equivalents. Certainty Equivalence is the minimum amount of money a decision maker would require as a lump sum payment to forgo a risky alternative, thus the decision maker is indifferent between the certainty equivalent and the future payoff of the risky alternative (Richardson et al., 2004). The value of the certainty equivalent for any given risky alternative is dependent upon the expected utility function of the decision maker and the decision maker's level of risk aversion (Richardson et al., 2004). The Certainty Equivalence can be analyzed at varying levels of risk aversion. The value of the Risk Aversion Coefficient (RAC) can be interpreted as:

$RAC < 0$ risk loving

$RAC = 0$ risk indifferent

$RAC > 0$ risk averse

A stronger attitude toward risk is inferred as the absolute value of the RAC increases (Richardson et al., 2004).

3. RESULTS

3.1. Results Overview

Empirical distributions were developed by utilizing price and cost per acre data from the model used by the aerial applicator. This was done by holding certain variables constant and letting price fluctuate as acres were changed which was discussed in the previous section. We did this for the SH, MH and the LH at profit margins of 5%, 10%, 15% and 20%. This gave us 40 observations for each of the 12 scenarios from which to develop the empirical distributions. We used the =EMP() function found in SIMETAR which assumes a continuous distribution whereby interpolating between the specified points on the distribution using the cumulative distribution probabilities (Richardson et al., 2008). These empirical distributions were then simulated 500 times to develop the CDF and PDF graphs for profit per acre variable.

The results from the twelve scenarios run will be discussed in this section. First, we will look at individual PDF and CDF graphs for each scenario. Next, each aircraft will be compared across all profit margins and then all aircraft will be compared at a given profit margin.

The PDF is the density of simulated profit per acre using empirical distribution. We use a 95% confidence interval which means that 95% of the time the realized value will be between the upper quantile and the lower quantile. Which means that 97.5% of the time, the realized value will be above the lower quantile and 97.5% of the time, the realized value will be below the upper quantile. We also acquire the mean which is what will occur on average. The CDF is another tool to analyze risky alternatives and is similar to a PDF. It shows the probability of profit per acre between the lower and upper bounds.

3.2. Probability Density Function (PDF) and Cumulative Distribution Function (CDF) Results

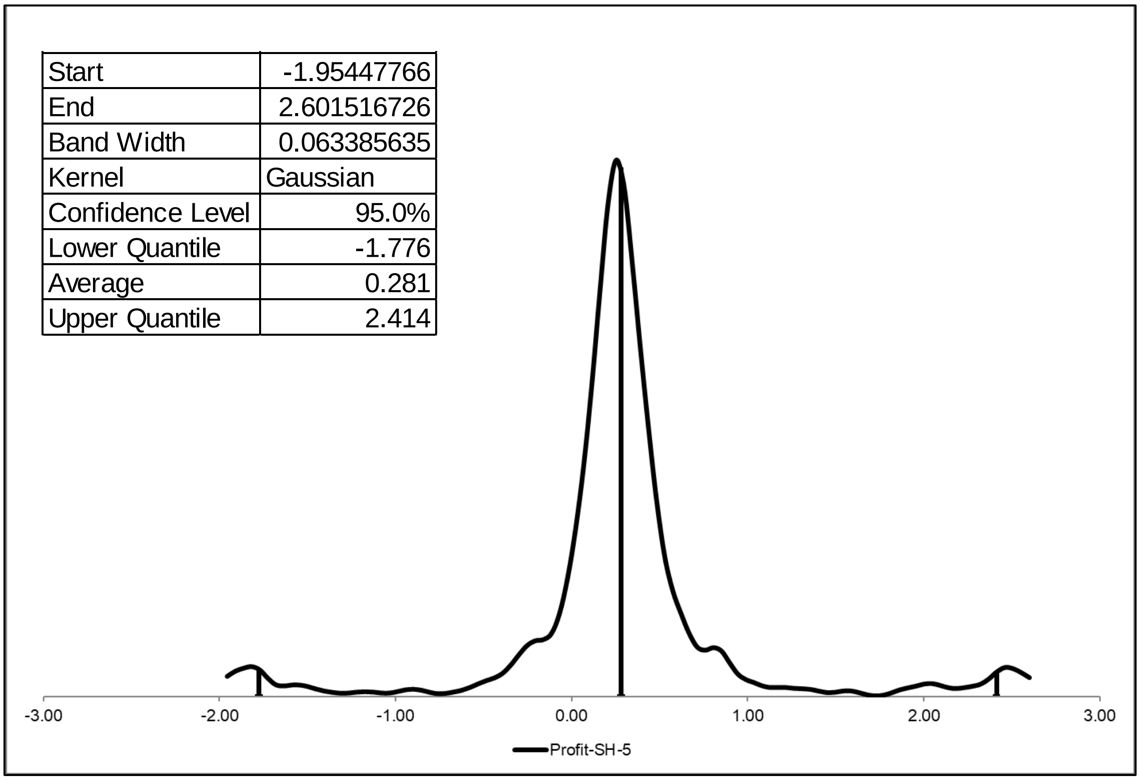

Figure 3.1 Probability Density Function (PDF) Approximation Profit per Acre SH 5%

In scenario one, 95% of the time we will observe a profit between a loss of $1.78 (the lower quantile) and $2.41 (the upper quantile) with an average profit per acre of $0.28.

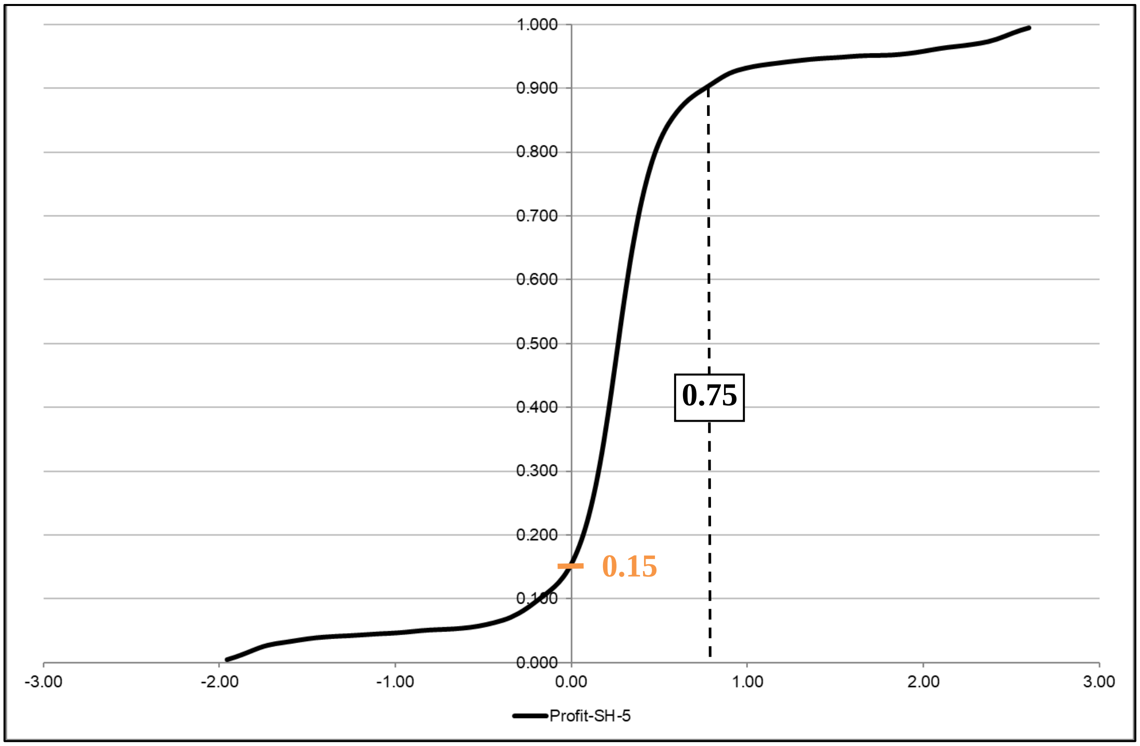

Figure 3.2 Cumulative Distribution Function (CDF) Approximation Profit per Acre SH 5%

Shown in the Figure 3.2, roughly 15% of the time a loss per acre will be observed. Around 75% of the time a profit per acre between $0 and $0.75 will be observed and roughly 10% of the time a profit per acre will be observed above $0.75.

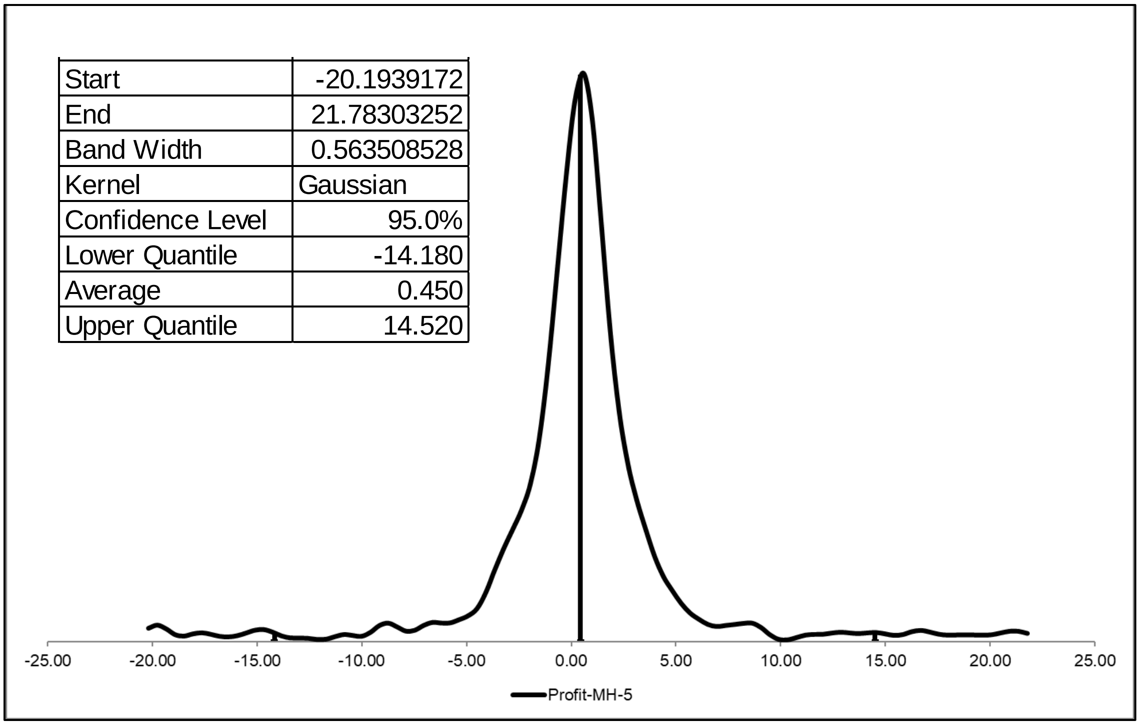

Figure 3.3 Probability Density Function (PDF) Approximation Profit per Acre MH 5%

In scenario two, 95% of the time we will observe a profit between a loss of $14.18 (the lower quantile) and $14.52 (the upper quantile) with an average profit per acre of $0.45.

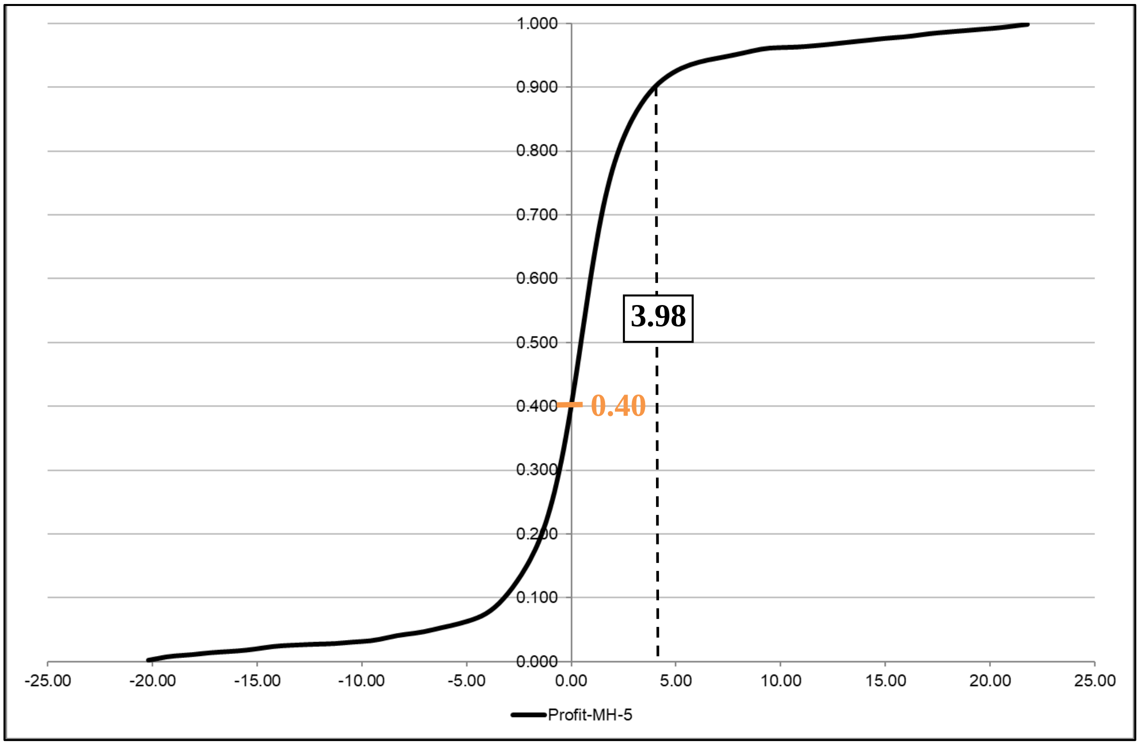

Figure 3.4 Cumulative Distribution Function (CDF) Approximation Profit per Acre MH 5%

Shown in Figure 3.4, roughly 40% of the time a loss per acre will be observed. Around 50% of the time a profit per acre between $0 and $3.98 will be observed and roughly 10% of the time a profit per acre will be observed above $3.98.

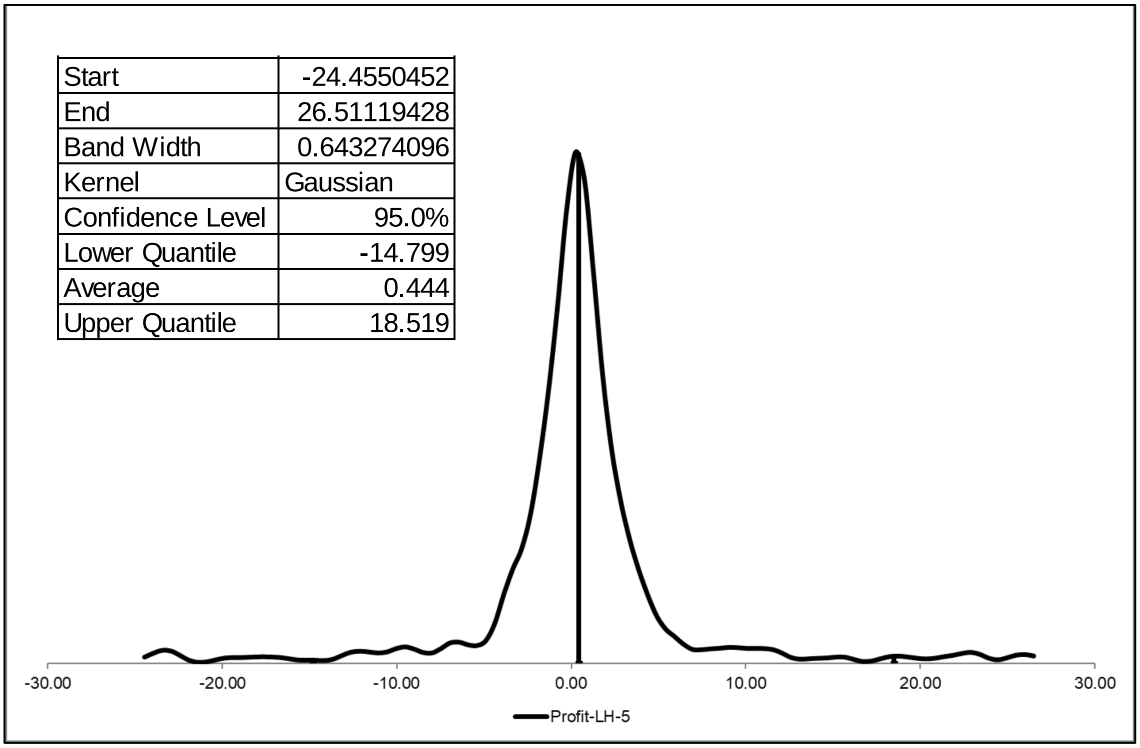

Figure 3.5 Probability Density Function (PDF) Approximation Profit per Acre LH 5%

In scenario three, 95% of the time we will observe a profit between a loss of $14.80 (the lower quantile) and $18.52 (the upper quantile) with an average profit per acre of $0.44.

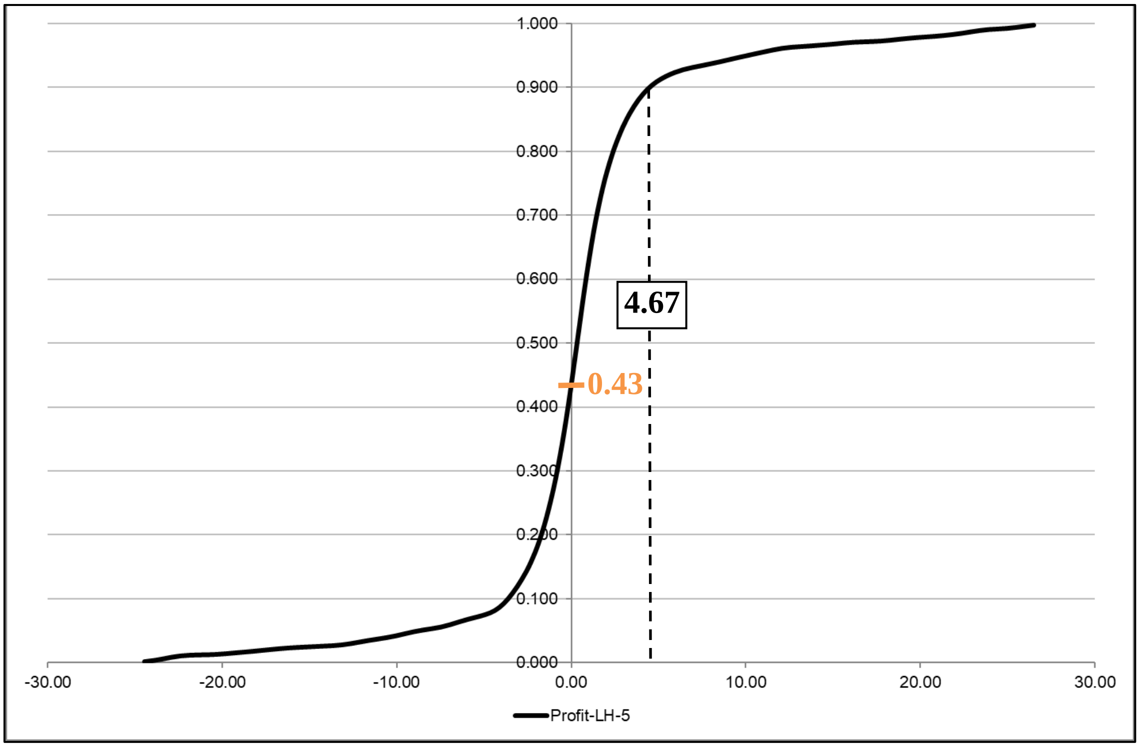

Figure 3.6 Cumulative Distribution Function (CDF) Approximation Profit per Acre LH 5%

Shown in Figure 3.6, roughly 43% of the time a loss per acre will be observed. Around 47% of the time a profit per acre between $0 and $4.67 will be observed and roughly 10% of the time a profit per acre will be observed above $4.67.

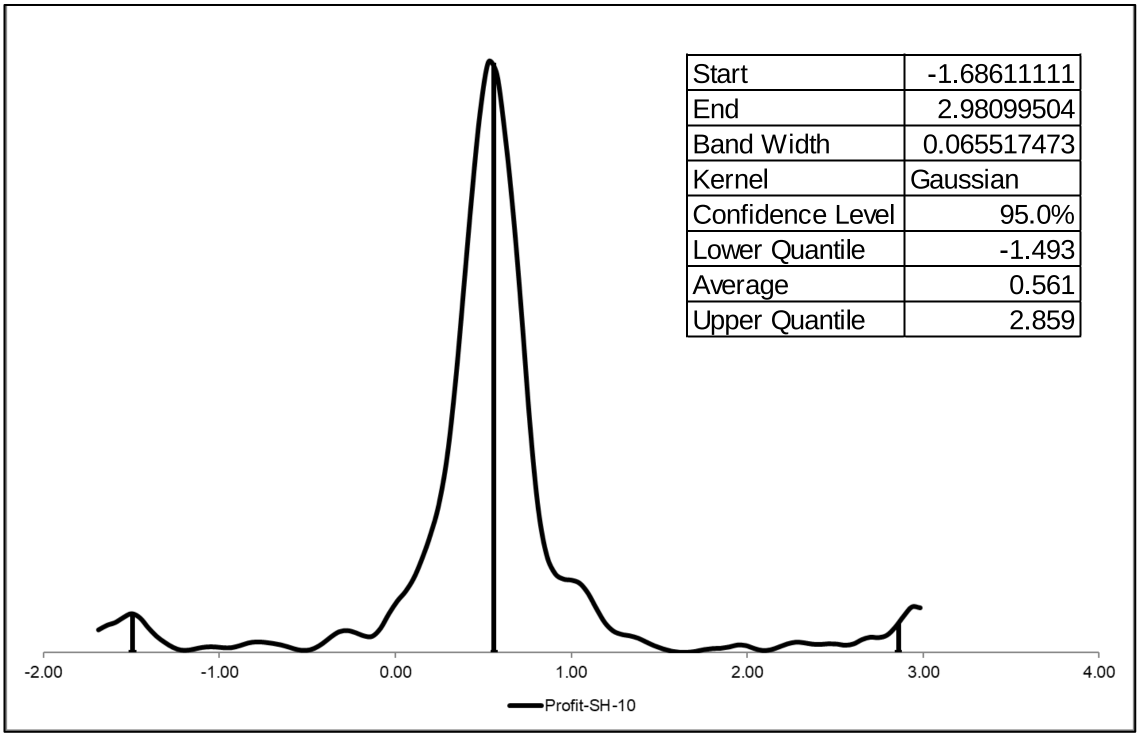

Figure 3.7 Probability Density Function (PDF) Approximation Profit per Acre SH 10%

In scenario four, 95% of the time we will observe a profit between a loss of $1.49 (the lower quantile) and $2.86 (the upper quantile) with an average profit per acre of $0.56.

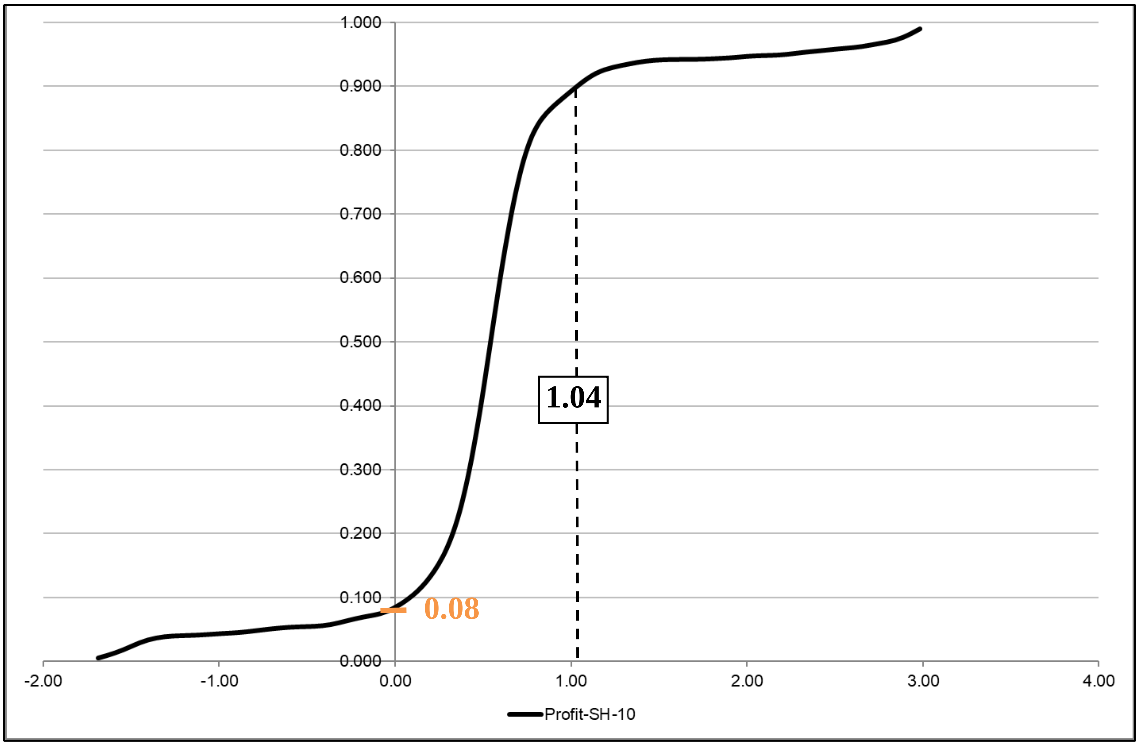

Figure 3.8 Cumulative Distribution Function (CDF) Approximation Profit per Acre SH 10%

Shown in Figure 3.8, roughly 8% of the time a loss per acre will be observed. Around 82% of the time a profit per acre between $0 and $1.04 will be observed and roughly 10% of the time a profit per acre will be observed above $1.04.

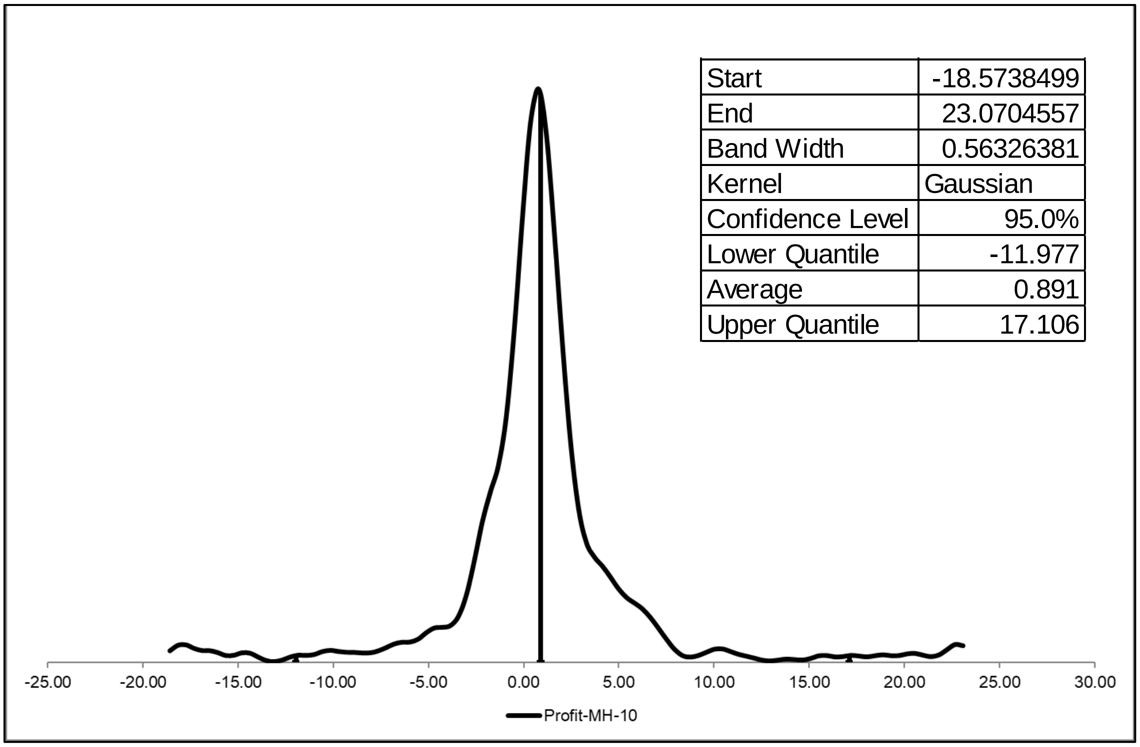

Figure 3.9 Probability Density Function (PDF) Approximation Profit per Acre MH 10%

In scenario five, 95% of the time we will observe a profit between a loss of $11.98 (the lower quantile) and $17.11 (the upper quantile) with an average profit per acre of $0.89.

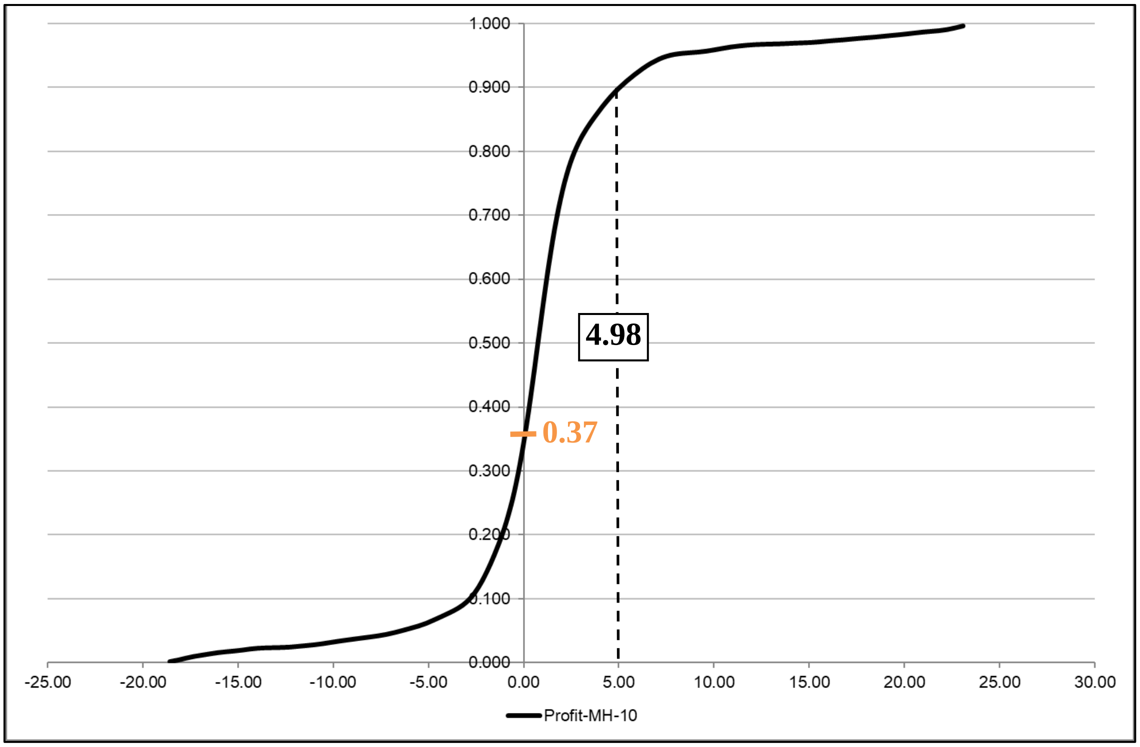

Figure 3.10 Cumulative Distribution Function (CDF) Approximation Profit per Acre MH 10%

Shown in Figure 3.10, roughly 37% of the time a loss per acre will be observed. Around 53% of the time a profit per acre between $0 and $4.98 will be observed and roughly 10% of the time a profit per acre will be observed above $4.98.

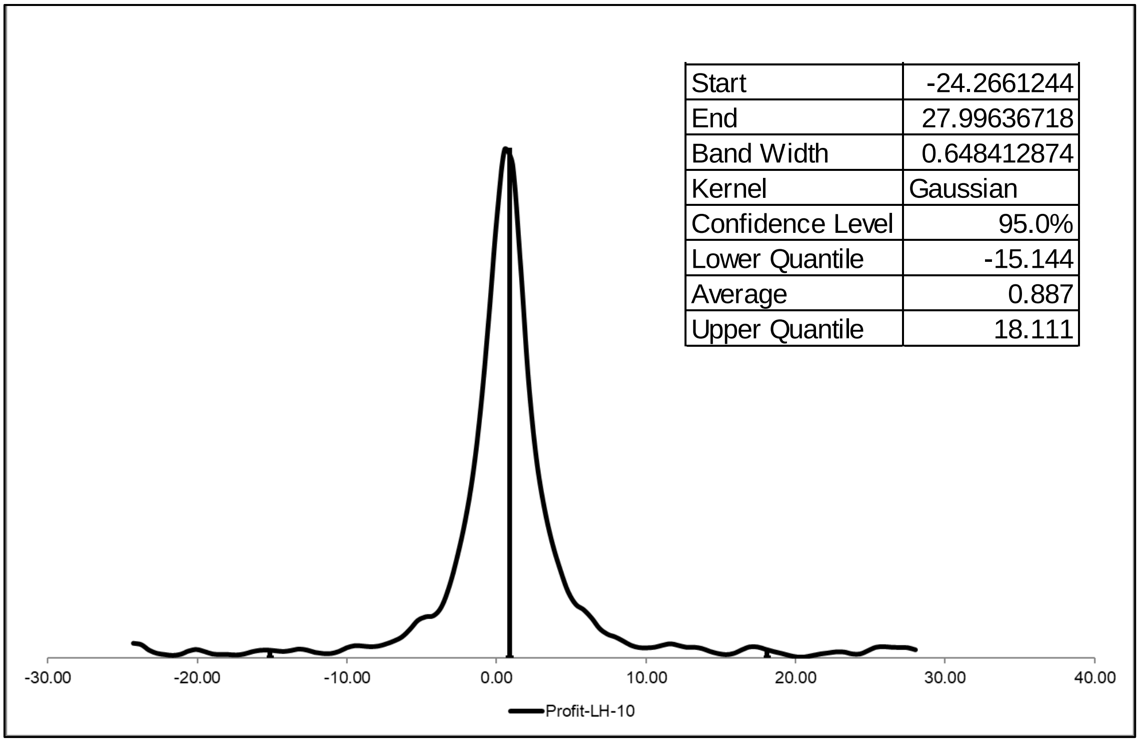

Figure 3.11 Probability Density Function (PDF) Approximation Profit per Acre LH 10%

In scenario six, 95% of the time we will observe a profit between a loss of $15.14 (the lower quantile) and $8.11 (the upper quantile) with an average profit per acre of $0.89.

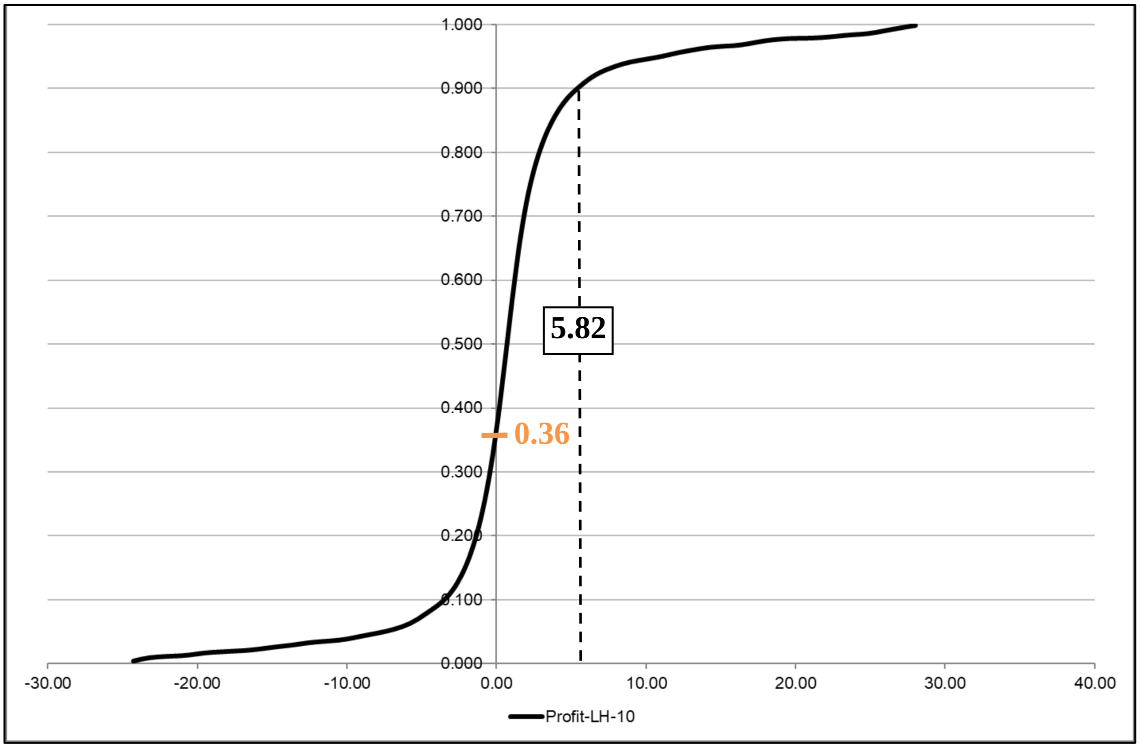

Figure 3.12 Cumulative Distribution Function (CDF) Approximation Profit per Acre LH 10%

Shown in figure 3.12, roughly 36% of the time a loss per acre will be observed. Around 54% of the time a profit per acre between $0 and $5.82 will be observed and roughly 10% of the time a profit per acre will be observed above $5.82.

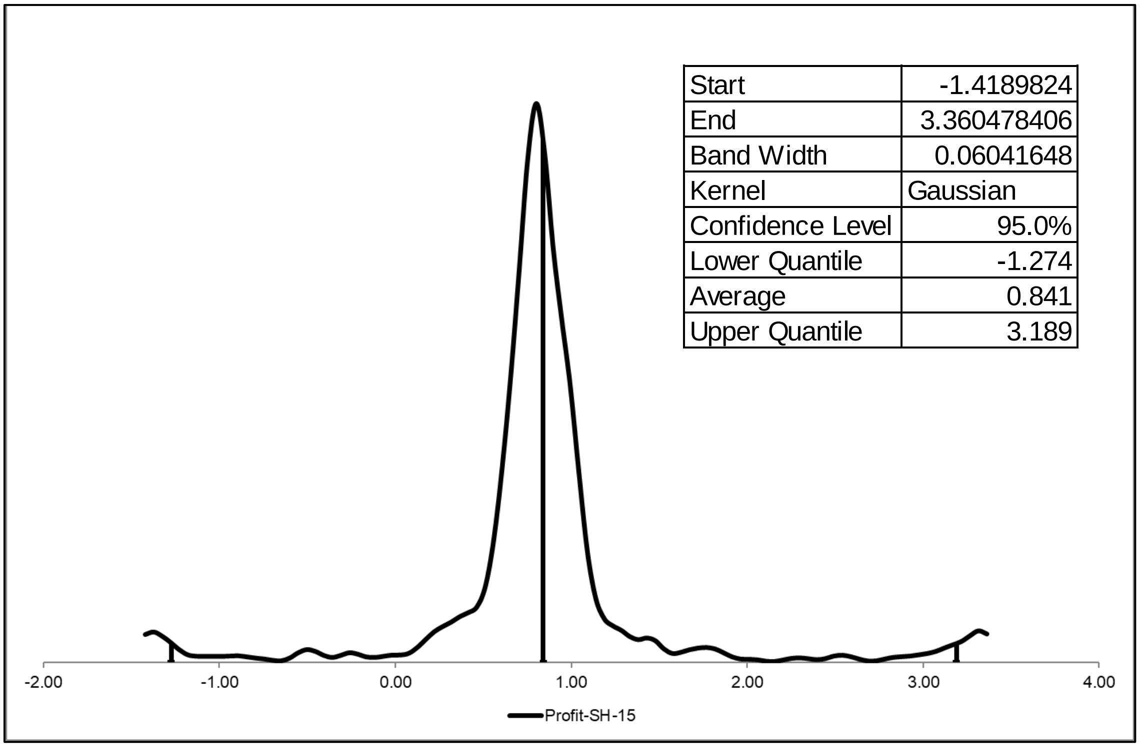

Figure 3.13 Probability Density Function (PDF) Approximation Profit per Acre SH 15%

In scenario seven, 95% of the time we will observe a profit between a loss of $1.27 (the lower quantile) and $3.19 (the upper quantile) with an average profit per acre of $0.84.

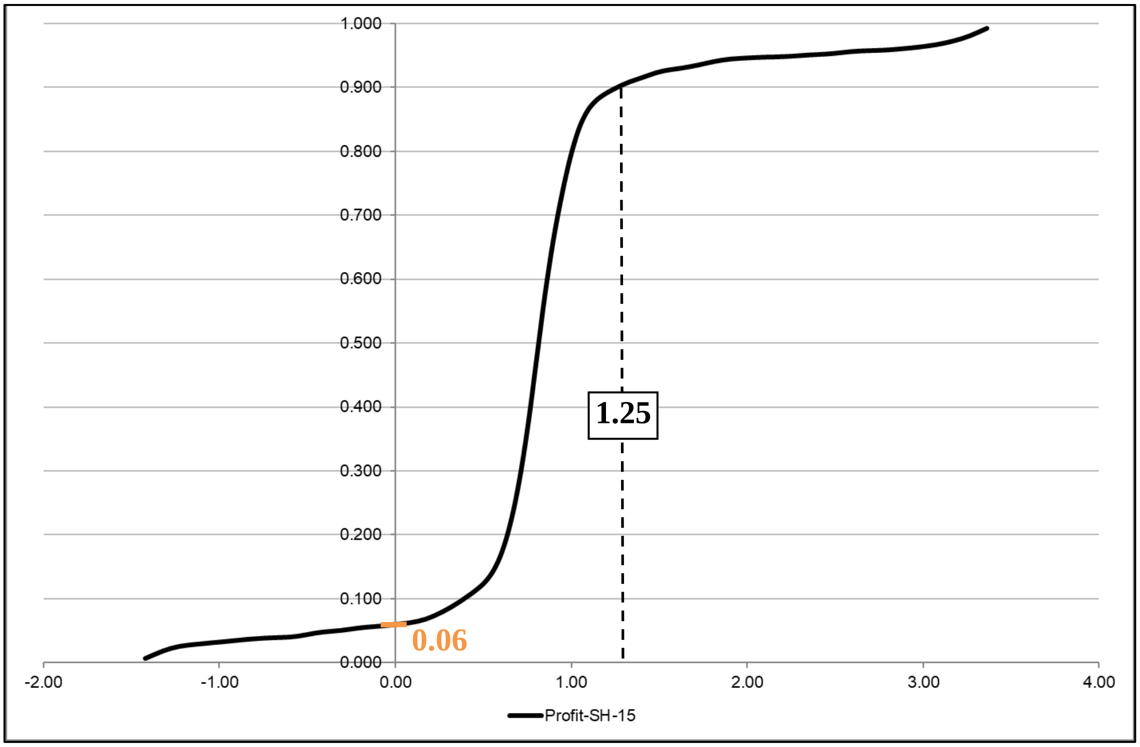

Figure 3.14 Cumulative Distribution Function (CDF) Approximation Profit per Acre SH 15%

Shown in figure 3.14, roughly 6% of the time a loss per acre will be observed. Around 84% of the time a profit per acre between $0 and $1.25 will be observed and roughly 10% of the time a profit per acre will be observed above $1.25.

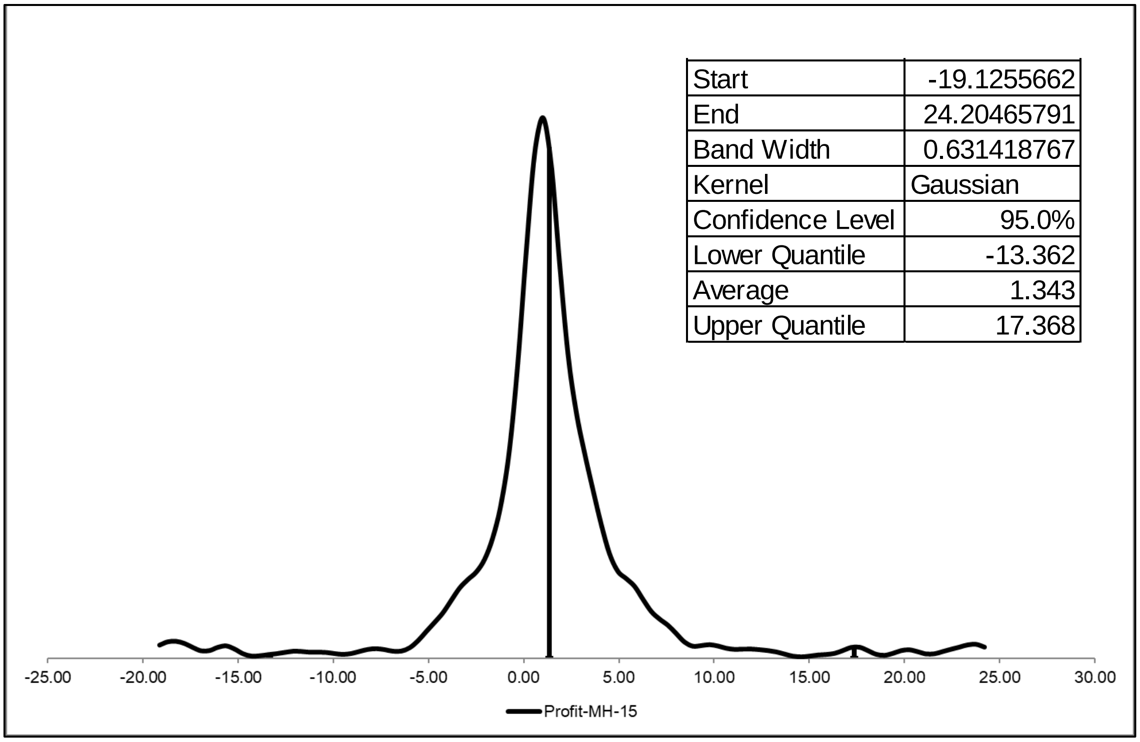

Figure 3.15 Probability Density Function (PDF) Approximation Profit per Acre MH 15%

In scenario eight, 95% of the time we will observe a profit between a loss of $13.36 (the lower quantile) and $17.37 (the upper quantile) with an average profit per acre of $1.34.

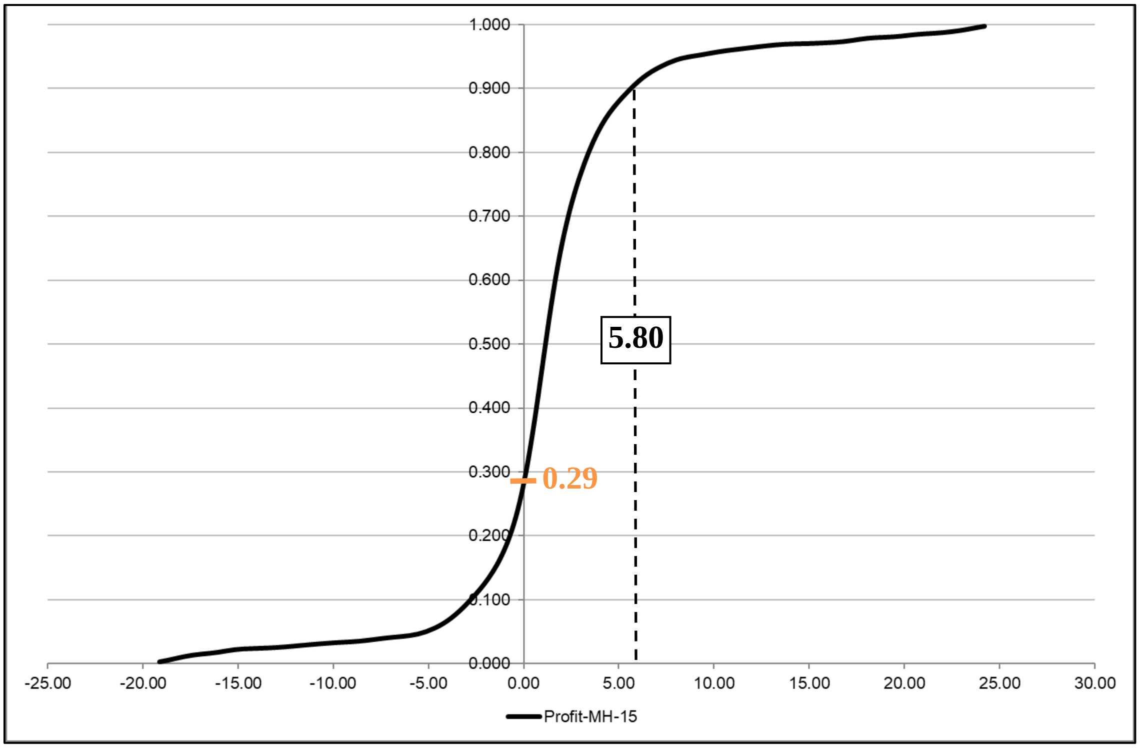

Figure 3.16 Cumulative Distribution Function (CDF) Approximation Profit per Acre MH 15%

Shown in Figure 3.16, roughly 29% of the time a loss per acre will be observed. Around 61% of the time a profit per acre between $0 and $5.80 will be observed and roughly 10% of the time a profit per acre will be observed above $5.80.

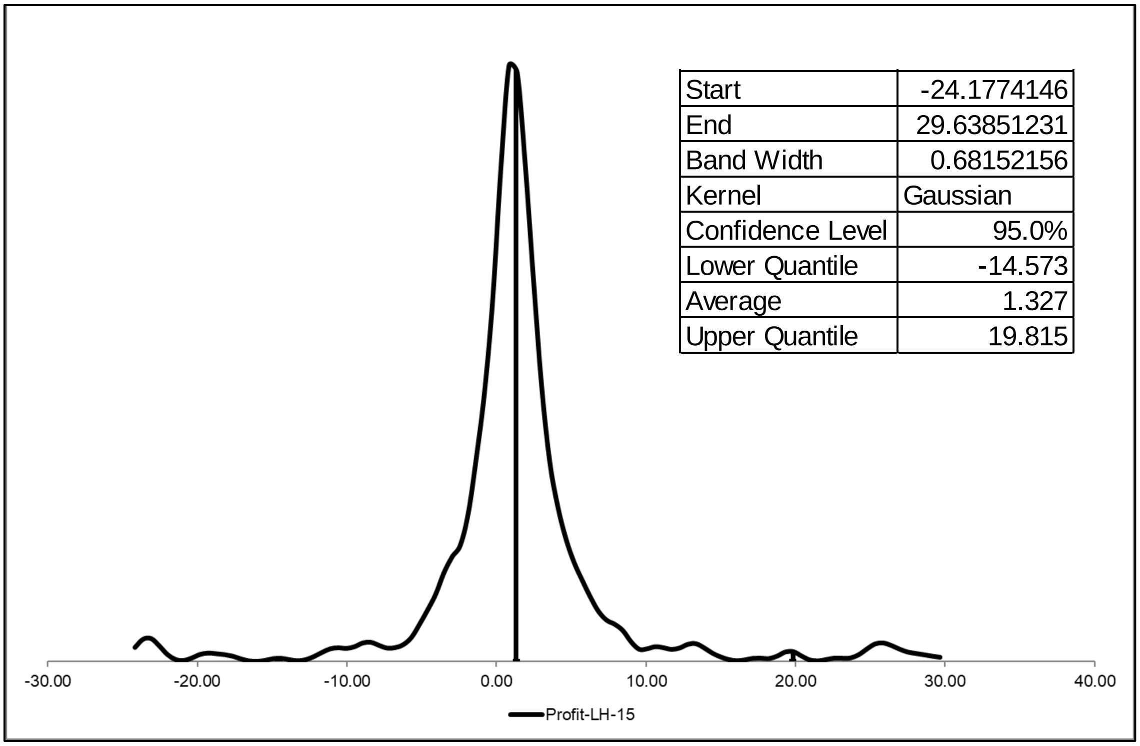

Figure 3.17 Probability Density Function (PDF) Approximation Profit per Acre LH 15%

In scenario nine, 95% of the time we will observe a profit between a loss of $14.57 (the lower quantile) and $19.82 (the upper quantile) with an average profit per acre of $1.33.

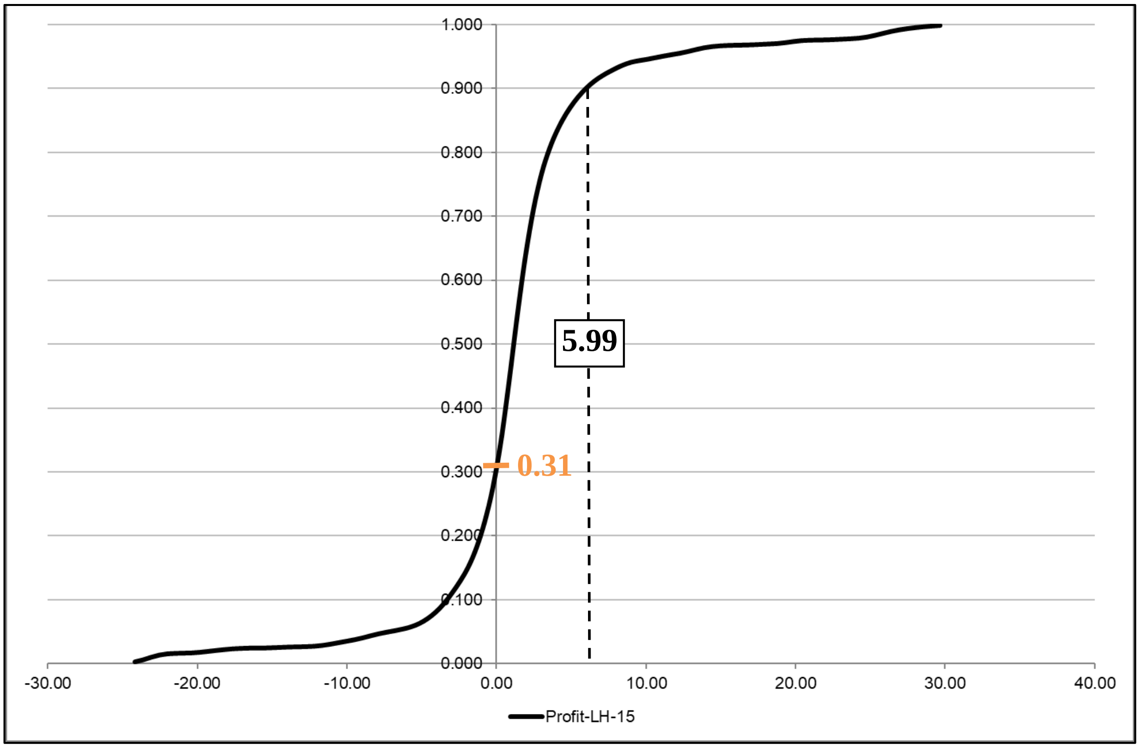

Figure 3.18 Cumulative Distribution Function (CDF) Approximation Profit per Acre LH 15%

Shown in Figure 3.18, roughly 31% of the time a loss per acre will be observed. Around 59% of the time a profit per acre between $0 and $5.99 will be observed and roughly 10% of the time a profit per acre will be observed above $5.99.

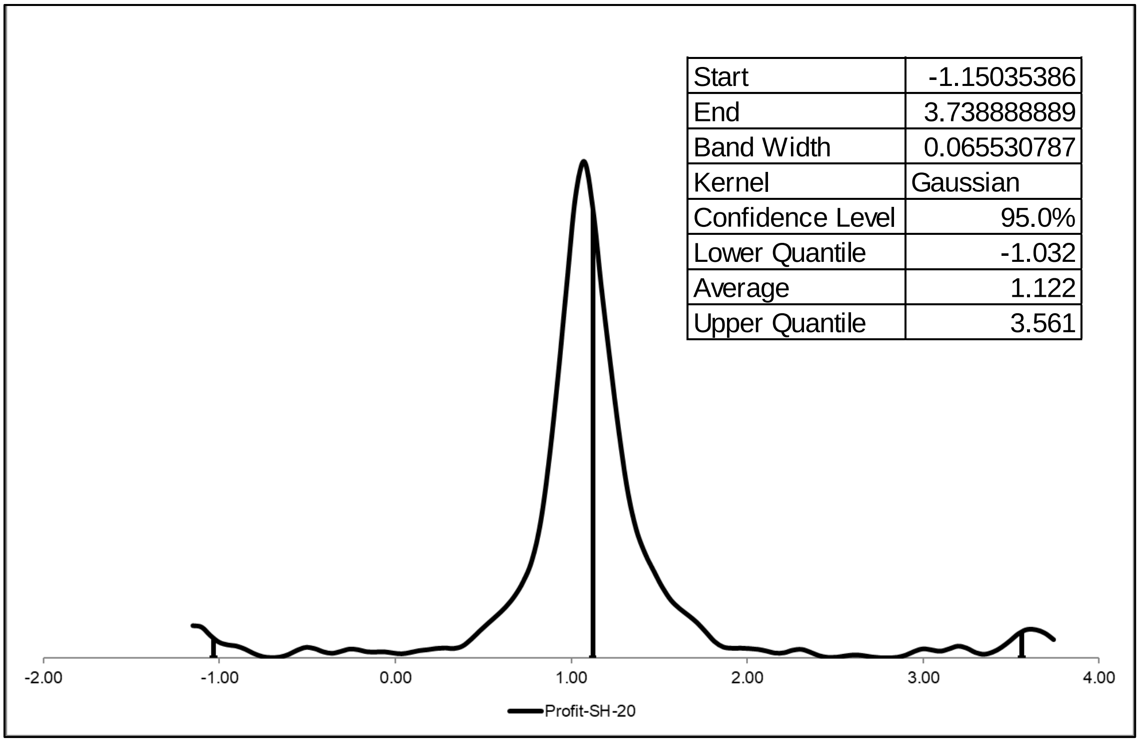

Figure 3.19 Probability Density Function (PDF) Approximation Profit per Acre SH 20%

In scenario ten, 95% of the time we will observe a profit between a loss of $1.03 (the lower quantile) and $3.56 (the upper quantile) with an average profit per acre of $1.12.

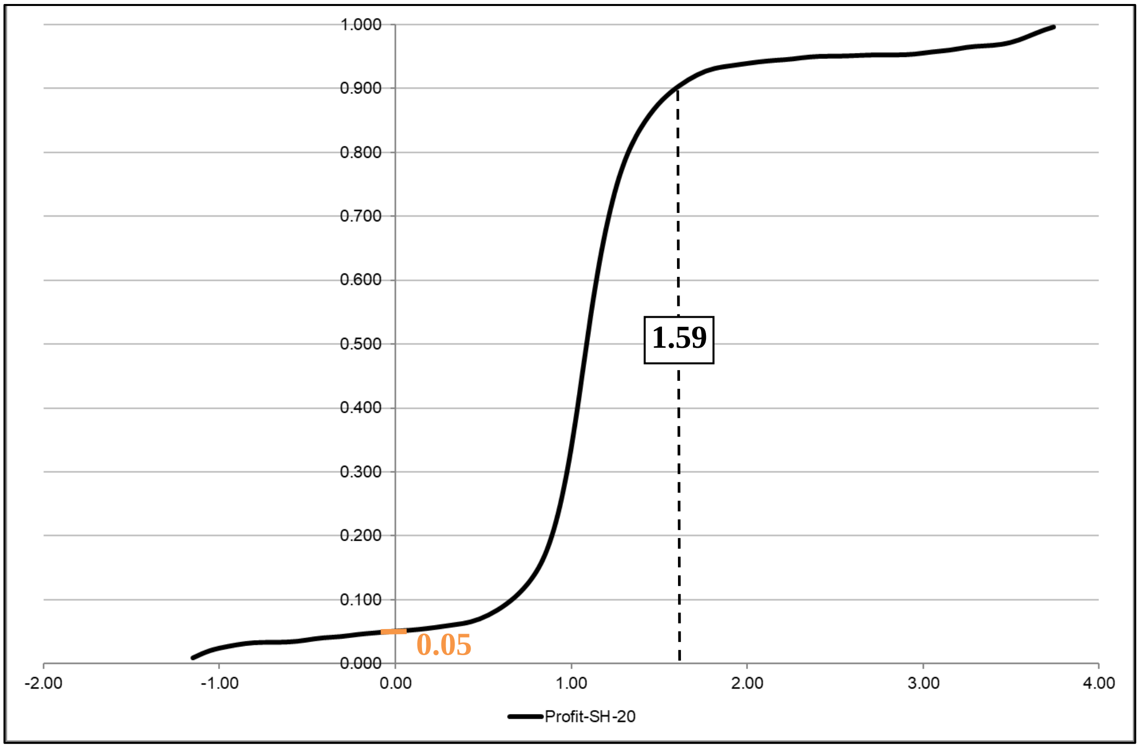

Figure 3.20 Cumulative Distribution Function (CDF) Approximation Profit per Acre SH 20%

Shown in Figure 3.20, roughly 5% of the time a loss per acre will be observed. Around 85% of the time a profit per acre between $0 and $1.59 will be observed and roughly 10% of the time a profit per acre will be observed above $1.59.

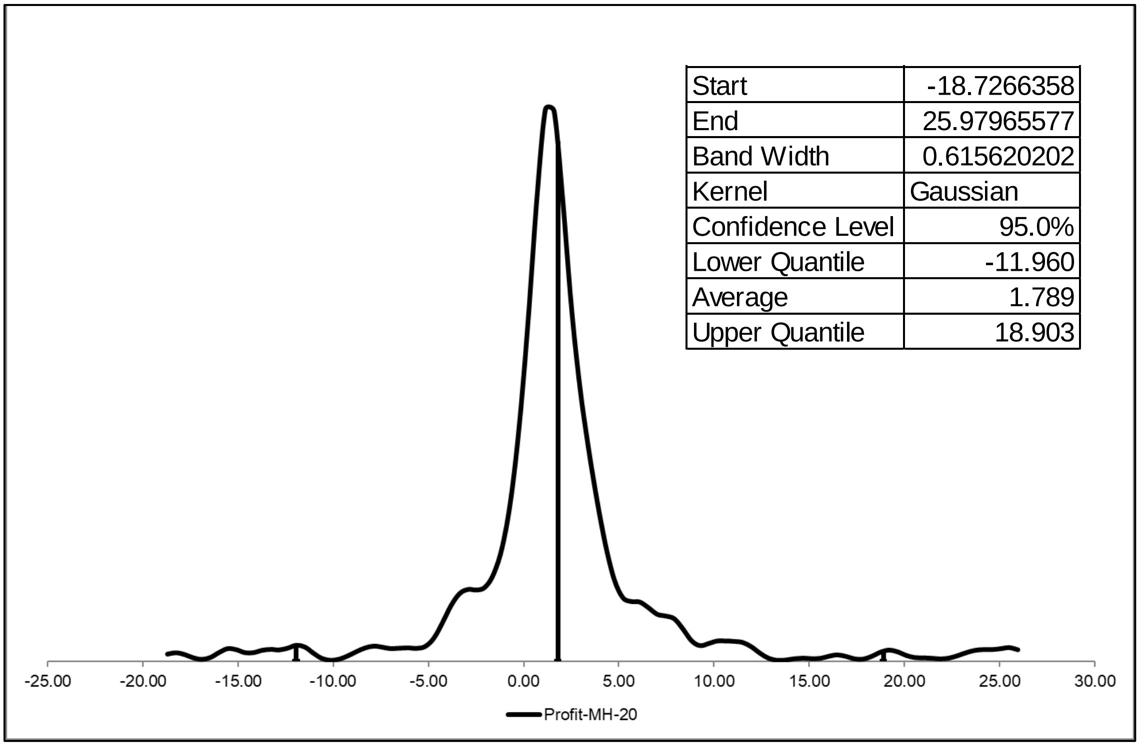

Figure 3.21 Probability Density Function (PDF) Approximation Profit per Acre MH 20%

In scenario eleven, 95% of the time we will observe a profit between a loss of $11.96 (the lower quantile) and $18.90 (the upper quantile) with an average profit per acre of $1.79.

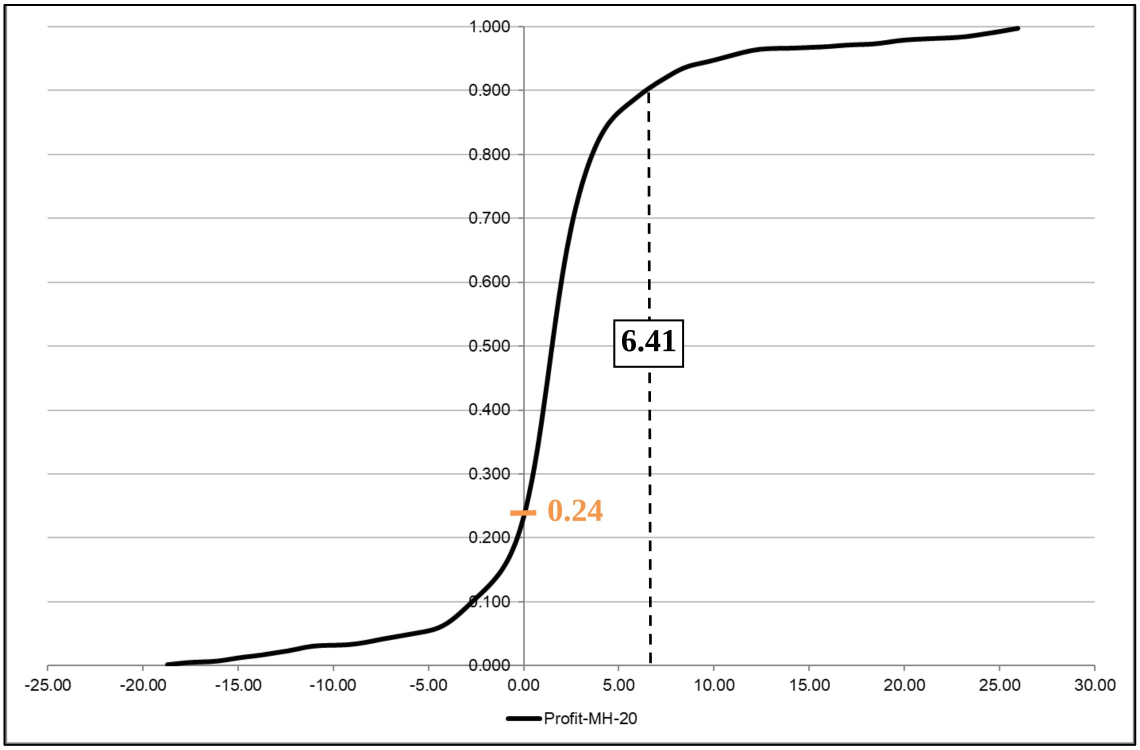

Figure 3.22 Cumulative Distribution Function (CDF) Approximation Profit per Acre MH 20%

Shown in Figure 3.22, roughly 24% of the time a loss per acre will be observed. Around 66% of the time a profit per acre between $0 and $6.41 will be observed and roughly 10% of the time a profit per acre will be observed above $6.41.

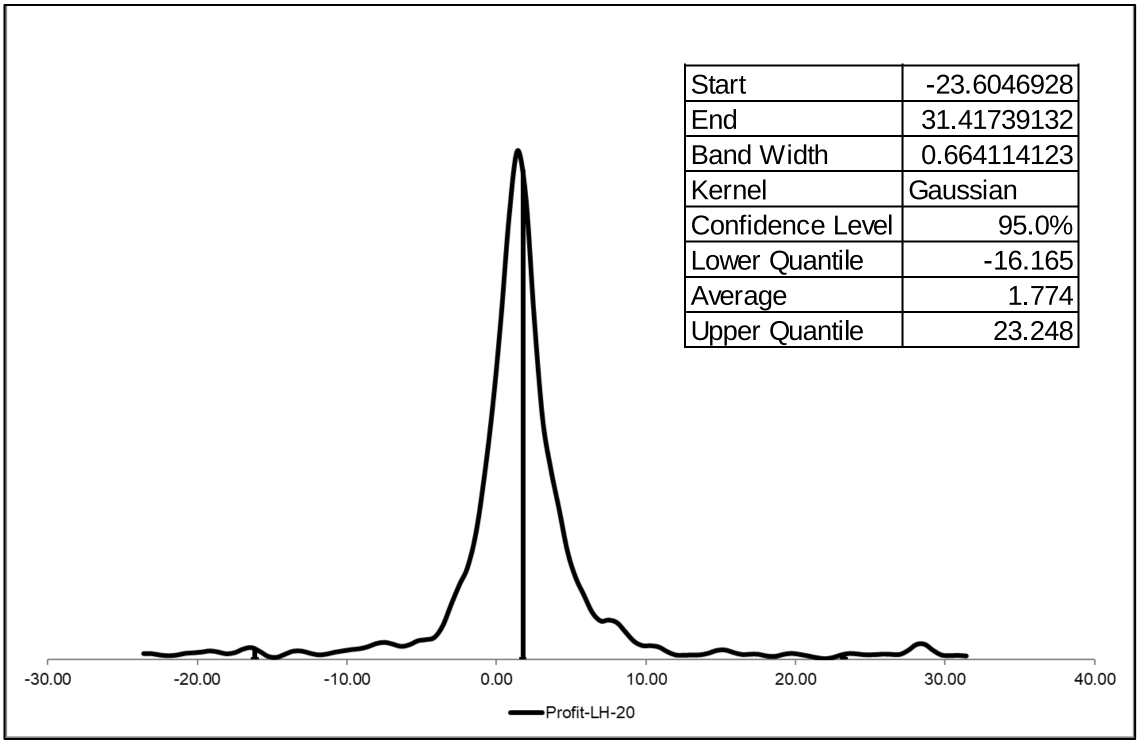

Figure 3.23 Probability Density Function (PDF) Approximation Profit per Acre LH 20%

In scenario twelve, 95% of the time we will observe a profit between a loss of $16.17 (the lower quantile) and $23.25 (the upper quantile) with an average profit per acre of $1.77.

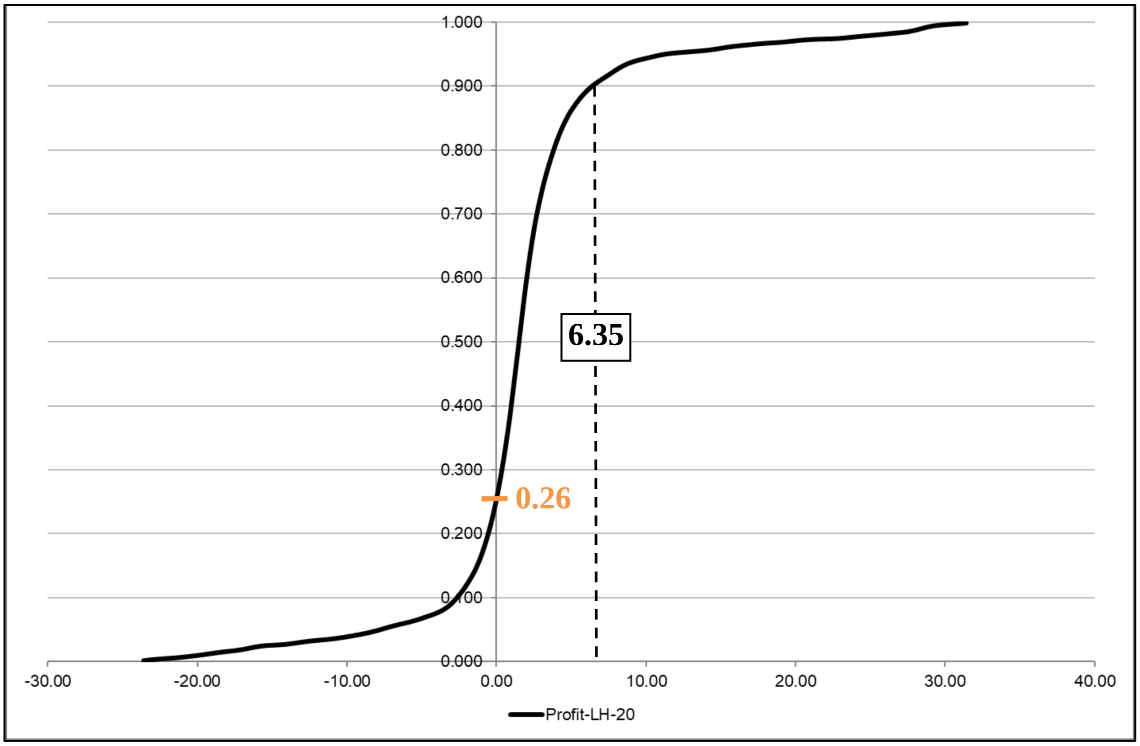

Figure 3.24 Cumulative Distribution Function (CDF) Approximation Profit per Acre LH 20%

Shown in Figure 3.24, roughly 26% of the time a loss per acre will be observed. Around 64% of the time a profit per acre between $0 and $6.35 will be observed and roughly 10% of the time a profit per acre will be observed above $6.35.

After developing PDFs and CDFs, CDFs were compared in various ways while accounting for risk aversion. Each aircraft was compared against itself at various profit margins and, additionally, each aircraft was compared against the other aircraft at each profit margin. This was accomplished using the SDRF and the SERF tests.

3.3. Stochastic Dominance with Respect to a Function (SDRF) Test Results

Figure 3.25 shows a comparison of the CDFs for the SH at five, ten, fifteen and twenty percent profit margins. As seen in Figure 3.25 and Table 3.1, the most preferred scenario from the risk averse to the risk loving is operating at a profit margin of twenty percent. The next most preferred is operating at a fifteen percent profit margin, then operating at a ten percent profit margin. Finally, the least preferred scenario is operating at a five percent profit margin.

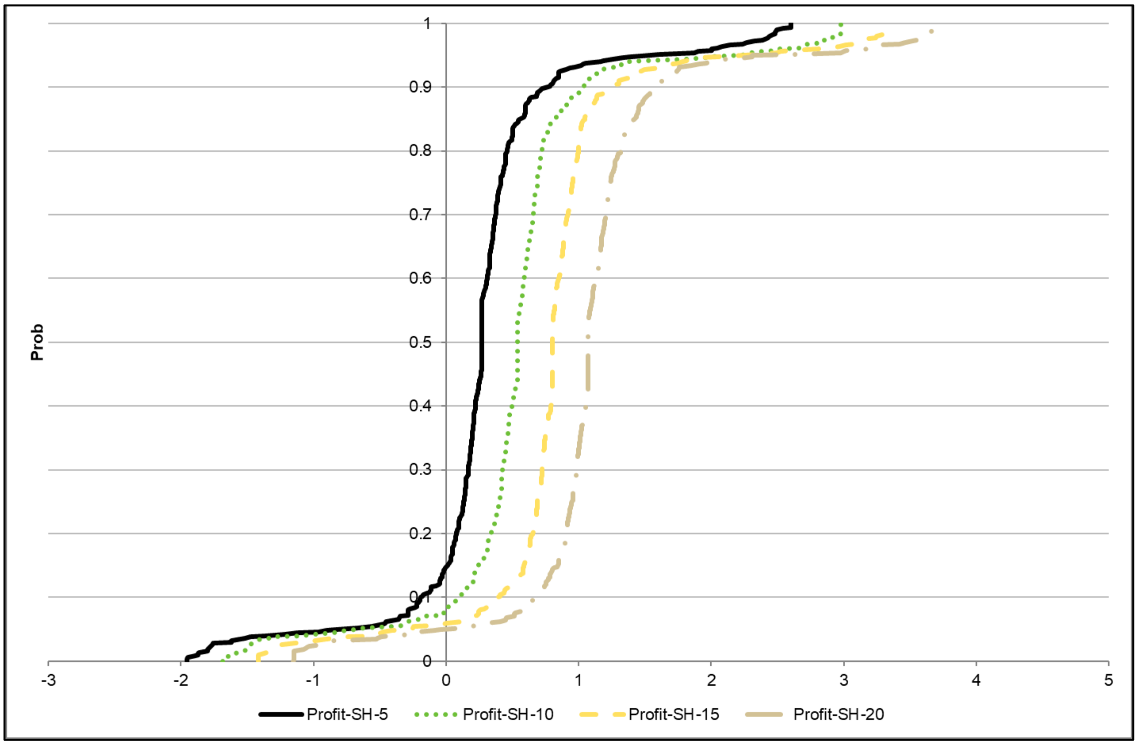

Figure 3.25 Comparison of Four Cumulative Distribution Function (CDF) Series for SH at 5%, 10%, 15% and 20% Profit Margin

Table 3.1 Analysis of Stochastic Dominance with Respect to a Function (SDRF) for SH at 5%, 10%, 15% and 20% Profit Margin

Analysis of Stochastic Dominance with Respect to a Function (SDRF)					
	Efficient Set Based on SDRF at			Efficient Set Based on SDRF at	
	Lower RAC	**-2**		Upper RAC	**2**
	Name	Level of Preference		Name	Level of Preference
1	Price-SH-20	Most Preferred	1	Price-SH-20	Most Preferred
2	Price-SH-15	2nd Most Preferred	2	Price-SH-15	2nd Most Preferred
3	Price-SH-10	3rd Most Preferred	3	Price-SH-10	3rd Most Preferred
4	Price-SH-5	Least Preferred	4	Price-SH-5	Least Preferred

SDRF: Stochastic Dominance with Respect to a Function
RAC: Risk Aversion Coefficient

Figure 3.26 shows a comparison of the CDFs for the MH at five, ten, fifteen and twenty percent profit margins. As seen Figure 3.26 and Table 3.2, the most preferred scenario from the risk averse to the risk loving is operating at a profit margin of twenty percent. The next most preferred is operating at a fifteen percent profit margin, then operating at a ten percent profit margin. Finally, the least preferred scenario is operating at a five percent profit margin.

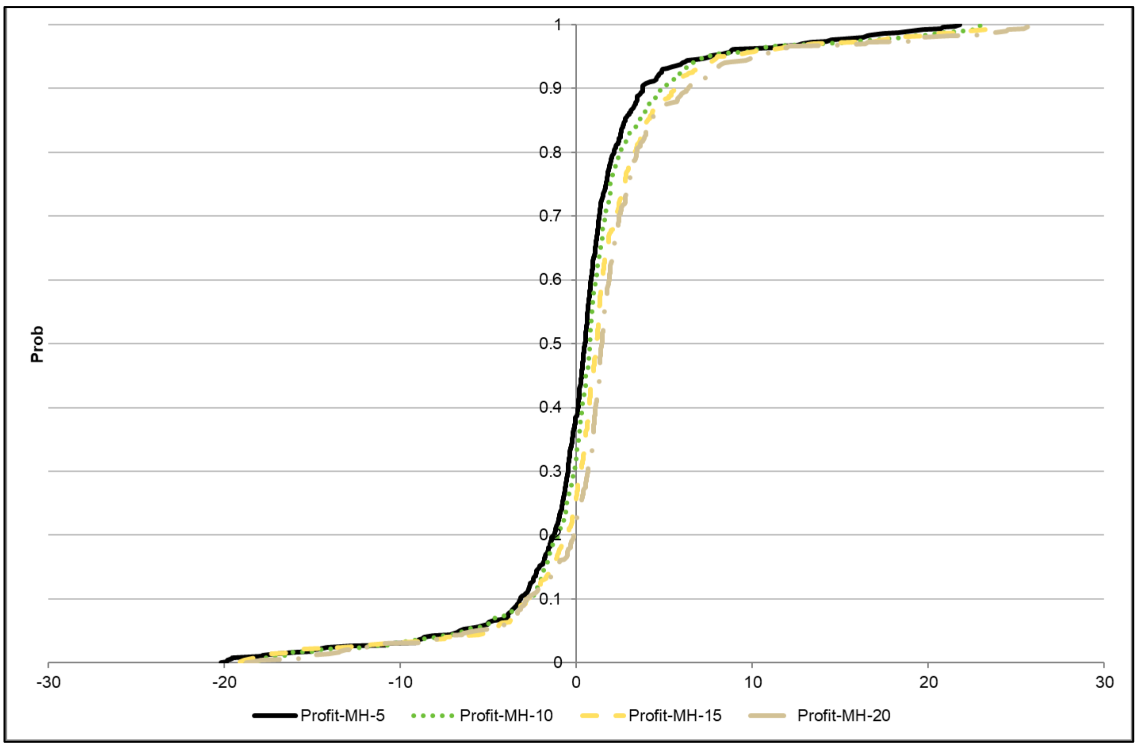

Figure 3.26 Comparison of Four Cumulative Distribution Function (CDF) Series for MH at 5%, 10%, 15% and 20% Profit Margin

Table 3.2 Analysis of Stochastic Dominance with Respect to a Function (SDRF) for MH at 5%, 10%, 15% and 20% Profit Margin

Analysis of Stochastic Dominance with Respect to a Function (SDRF)					
	Efficient Set Based on SDRF at			Efficient Set Based on SDRF at	
	Lower RAC	**-2**		Upper RAC	**2**
	Name	Level of Preference		Name	Level of Preference
1	Price-MH-20	Most Preferred	1	Price-MH-20	Most Preferred
2	Price-MH-15	2nd Most Preferred	2	Price-MH-15	2nd Most Preferred
3	Price-MH-10	3rd Most Preferred	3	Price-MH-10	3rd Most Preferred
4	Price-MH-5	Least Preferred	4	Price-MH-5	Least Preferred

SDRF: Stochastic Dominance with Respect to a Function
RAC: Risk Aversion Coefficient

Figure 3.27 shows a comparison of the CDFs for the LH at five, ten, fifteen and twenty percent profit margins. As seen in Figure 3.27 and Table 3.3, the most preferred scenario from the risk averse to the risk loving is operating at a profit margin of twenty percent. The next most preferred is operating at a fifteen percent profit margin, then operating at a ten percent profit margin. Finally, the least preferred scenario is operating at a five percent profit margin.

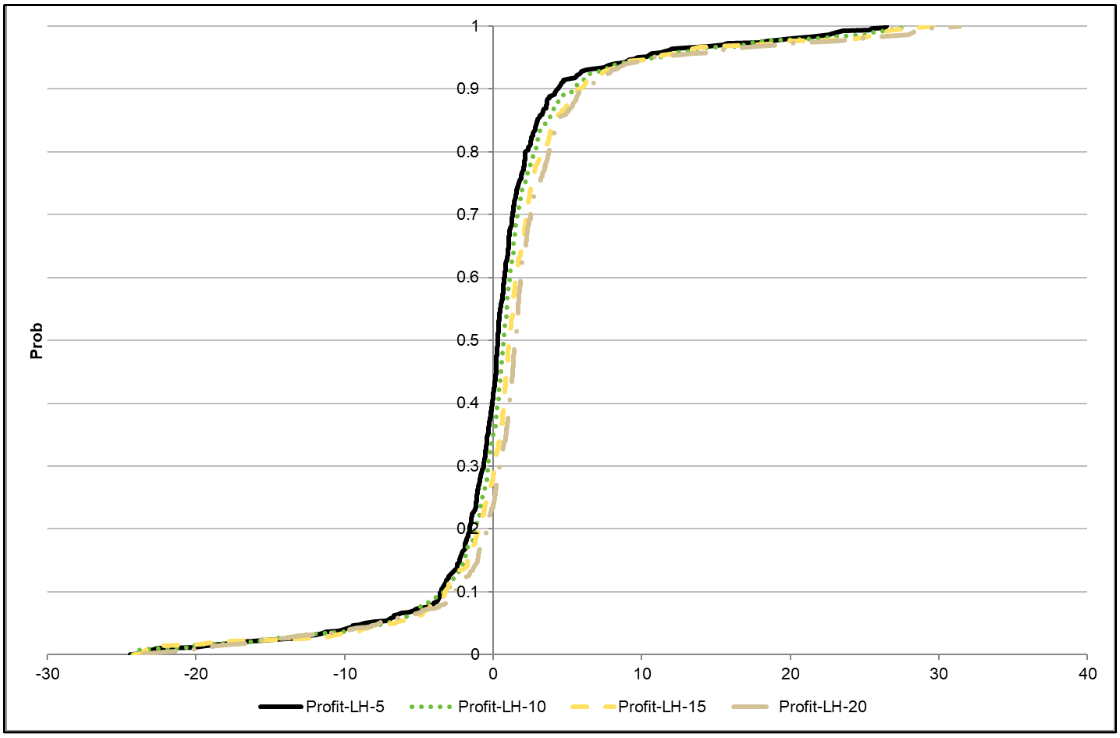

Figure 3.27 Comparison of Four Cumulative Distribution Function (CDF) Series for LH at 5%, 10%, 15% and 20% Profit Margin

Table 3.3 Analysis of Stochastic Dominance with Respect to a Function (SDRF) for LH at 5%, 10%, 15% and 20% Profit Margin

Analysis of Stochastic Dominance with Respect to a Function (SDRF)					
	Efficient Set Based on SDRF at			Efficient Set Based on SDRF at	
	Lower RAC	**-2**		Upper RAC	**2**
	Name	Level of Preference		Name	Level of Preference
1	Price-LH-20	Most Preferred	1	Price-LH-20	Most Preferred
2	Price-LH-15	2nd Most Preferred	2	Price-LH-15	2nd Most Preferred
3	Price-LH-10	3rd Most Preferred	3	Price-LH-10	3rd Most Preferred
4	Price-LH-5	Least Preferred	4	Price-LH-5	Least Preferred

SDRF: Stochastic Dominance with Respect to a Function
RAC: Risk Aversion Coefficient

Figure 3.28 shows a comparison of the CDFs for the SH, MH and LH at a five percent profit margin. As seen in Figure 3.28 and Table 3.4, the most preferred scenario at a profit margin of five percent for the risk averse is with the SH, while the most preferred scenario for the risk loving is with the LH.

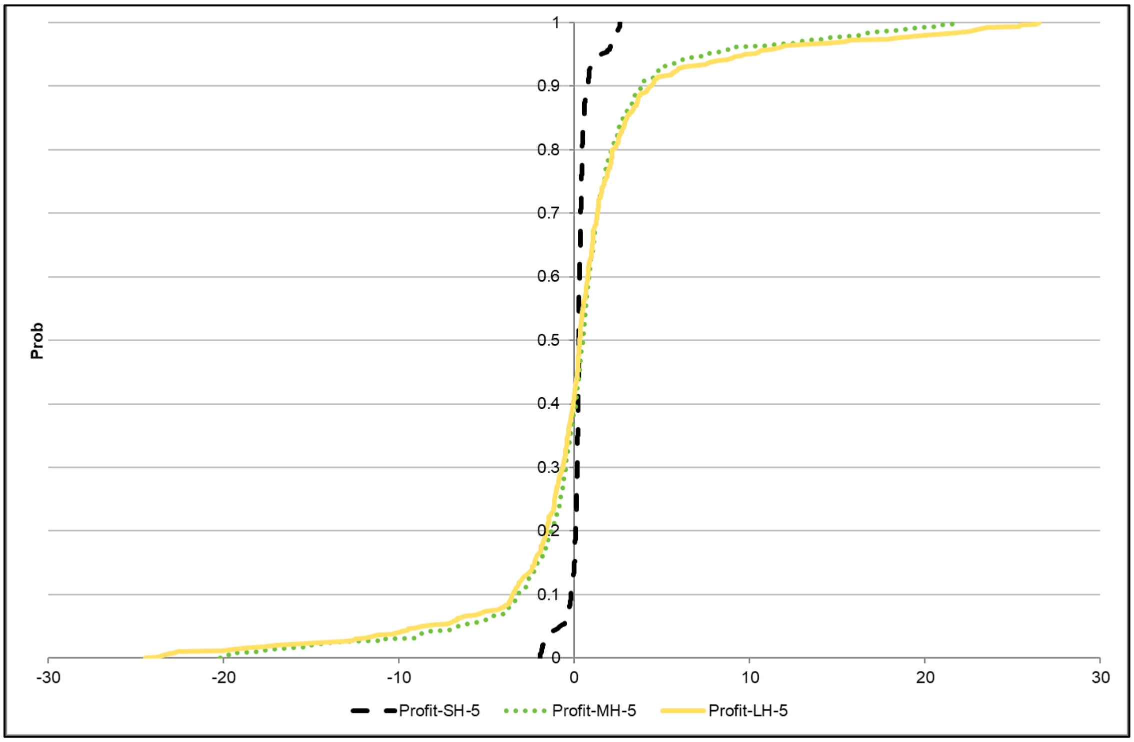

Figure 3.28 Comparison of Three Cumulative Distribution Function (CDF) Series for SH, MH and LH at 5% Profit Margin

Table 3.4 Analysis of Stochastic Dominance with Respect to a Function (SDRF) for SH, MH and LH at 5% Profit Margin

Analysis of Stochastic Dominance with Respect to a Function (SDRF)					
	Efficient Set Based on SDRF at			Efficient Set Based on SDRF at	
	Lower RAC	**-2**		Upper RAC	**2**
	Name	Level of Preference		Name	Level of Preference
1	Price-LH-5	Most Preferred	1	Price-SH-5	Most Preferred
2	Price-MH-5	2nd Most Preferred	2	Price-MH-5	2nd Most Preferred
3	Price-SH-5	3rd Most Preferred	3	Price-LH-5	3rd Most Preferred

SDRF: Stochastic Dominance with Respect to a Function
RAC: Risk Aversion Coefficient

Figure 3.29 shows a comparison of the CDFs for the SH, MH and LH at a ten percent profit margin. As seen in Figure 3.29 and Table 3.5, the most preferred scenario at a profit margin of ten percent for the risk averse is with the SH, while the most preferred scenario for the risk loving is with the LH.

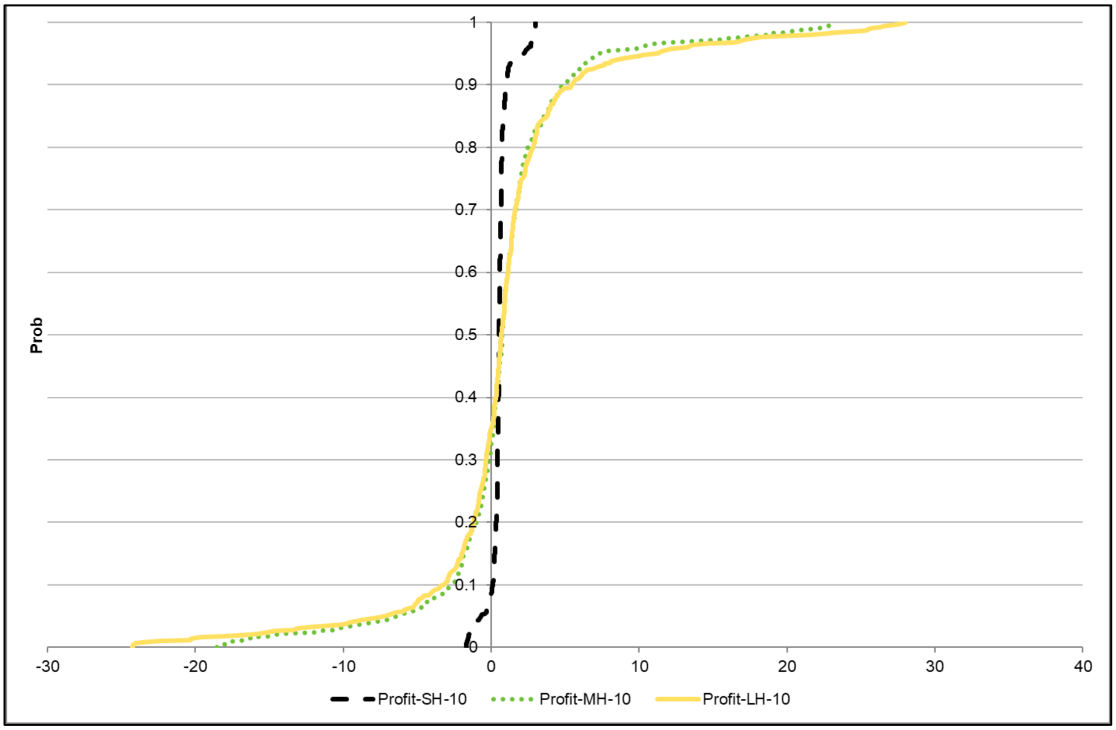

Figure 3.29 Comparison of Three Cumulative Distribution Function (CDF) Series for SH, MH and LH at 10% Profit Margin

Table 3.5 Analysis of Stochastic Dominance with Respect to a Function (SDRF) for SH, MH and LH at 10% Profit Margin

Analysis of Stochastic Dominance with Respect to a Function (SDRF)					
	Efficient Set Based on SDRF at			Efficient Set Based on SDRF at	
	Lower RAC	**-2**		Upper RAC	**2**
	Name	Level of Preference		Name	Level of Preference
1	Price-LH-10	Most Preferred	1	Price-SH-5	Most Preferred
2	Price-MH-10	2nd Most Preferred	2	Price-MH-5	2nd Most Preferred
3	Price-SH-10	3rd Most Preferred	3	Price-LH-5	3rd Most Preferred

SDRF: Stochastic Dominance with Respect to a Function
RAC: Risk Aversion Coefficient

Figure 3.30 shows a comparison of the CDFs for the SH, MH and LH at a fifteen percent profit margin. As seen in Figure 3.30 and Table 3.6, the most preferred scenario at a profit margin of fifteen percent for the risk averse is with the SH, while the most preferred scenario for the risk loving is with the LH.

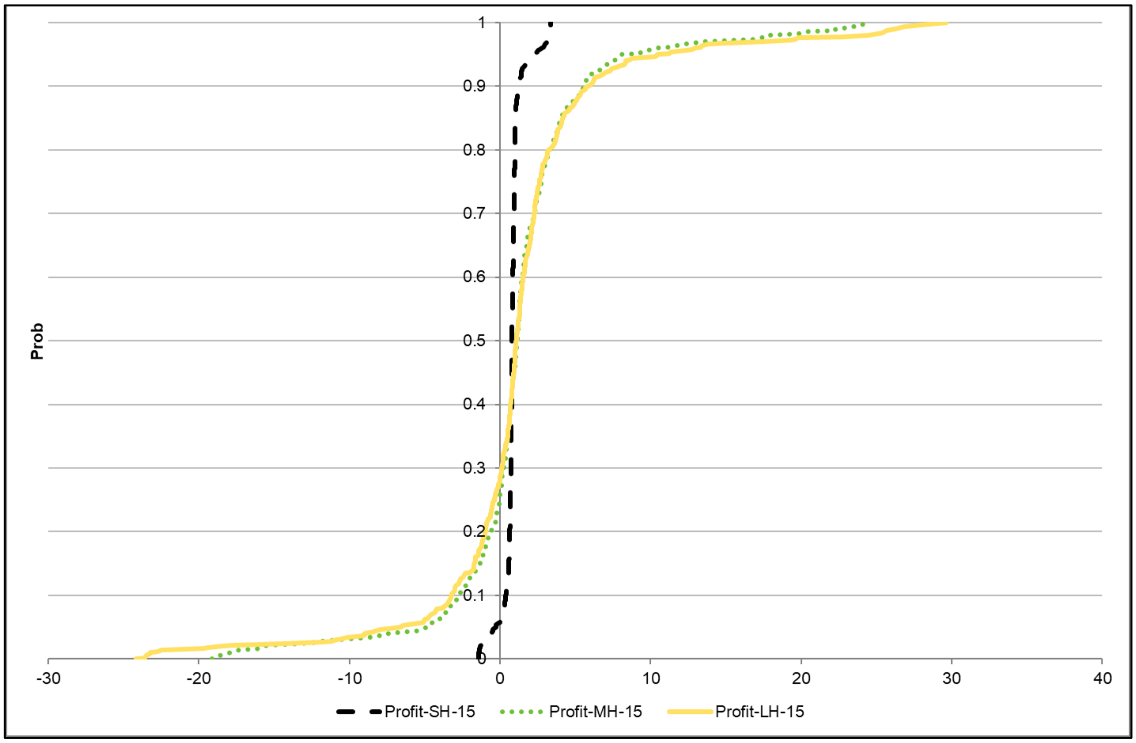

Figure 3.30 Comparison of Three Cumulative Distribution Function (CDF) Series for SH, MH and LH at 15% Profit Margin

Table 3.6 Analysis of Stochastic Dominance with Respect to a Function (SDRF) for SH, MH and LH at 15% Profit Margin

Analysis of Stochastic Dominance with Respect to a Function (SDRF)					
	Efficient Set Based on SDRF at			Efficient Set Based on SDRF at	
	Lower RAC	**-2**		Upper RAC	**2**
	Name	Level of Preference		Name	Level of Preference
1	Price-LH-15	Most Preferred	1	Price-SH-5	Most Preferred
2	Price-MH-15	2nd Most Preferred	2	Price-MH-5	2nd Most Preferred
3	Price-SH-15	3rd Most Preferred	3	Price-LH-5	3rd Most Preferred

SDRF: Stochastic Dominance with Respect to a Function
RAC: Risk Aversion Coefficient

Figure 3.31 shows a comparison of the CDFs for the SH, MH and LH at a twenty percent profit margin. As seen in Figure 3.31 and Table 3.7, the most preferred scenario at a profit margin of twenty percent for the risk averse is with the SH, while the most preferred scenario for the risk loving is with the LH.

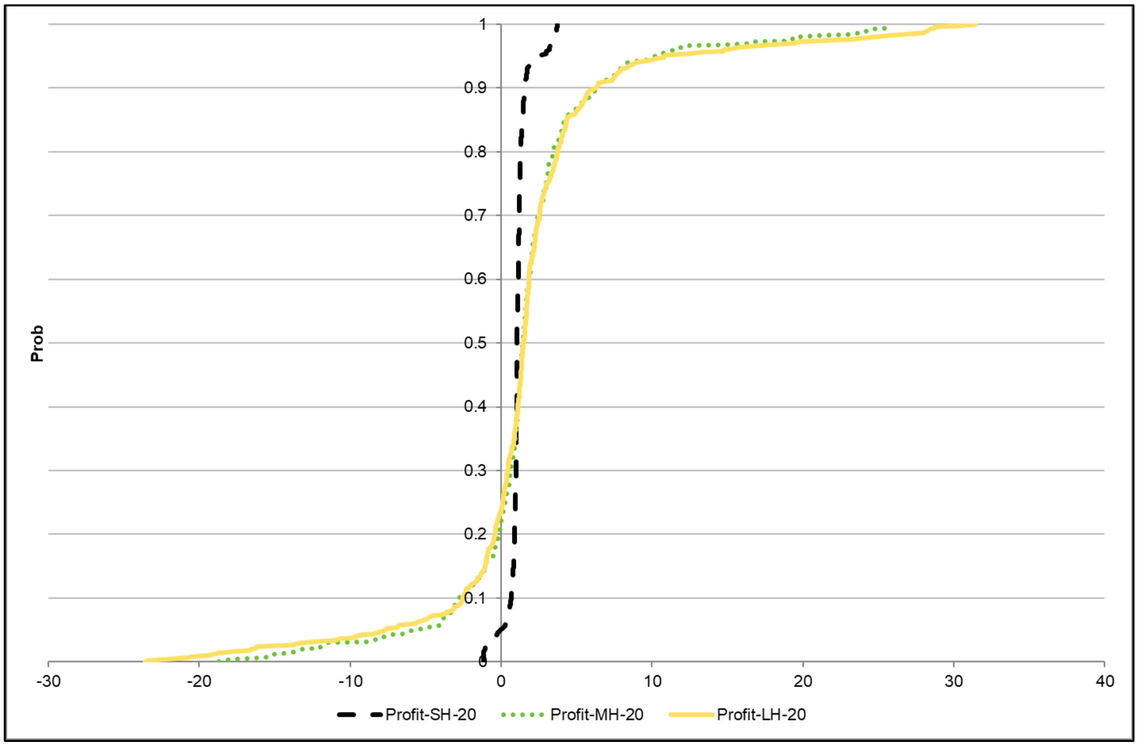

Figure 3.31 Comparison of Three Cumulative Distribution Function (CDF) Series for SH, MH and LH at 20% Profit Margin

Table 3.7 Analysis of Stochastic Dominance with Respect to a Function (SDRF) for SH, MH and LH at 20% Profit Margin

Analysis of Stochastic Dominance with Respect to a Function (SDRF)					
	Efficient Set Based on SDRF at			Efficient Set Based on SDRF at	
	Lower RAC	**-2**		Upper RAC	**2**
	Name	Level of Preference		Name	Level of Preference
1	Price-LH-20	Most Preferred	1	Price-SH-5	Most Preferred
2	Price-MH-20	2nd Most Preferred	2	Price-MH-5	2nd Most Preferred
3	Price-SH-20	3rd Most Preferred	3	Price-LH-5	3rd Most Preferred

SDRF: Stochastic Dominance with Respect to a Function
RAC: Risk Aversion Coefficient

3.4. Stochastic Efficiency with Respect to a Function (SERF) Test Results

The SERF test allows for the ranking of scenarios with given levels of risk. There is opportunity for higher profits per acre using the LH aircraft; however, there is also greater risk of loss. The risk-loving decision maker may choose the opportunity for higher profits with the LH aircraft despite the risks for higher losses while the risk-averse decision maker may choose to reduce the chance of higher losses at the expense of the opportunity for higher profits with the SH aircraft. This decision is based on each decision makers own choice for what level of risk he or she is willing to accept.

Figure 3.32 shows a chart generated by SIMETAR through the SERF test comparing certainty equivalents across all aircraft at a five percent profit margin. As we move from risk loving to risk averse, there is a shift from the preferred aircraft being the LH to the preferred aircraft being the SH. This occurs at the point of indifference where an applicator is indifferent to the associated risk.

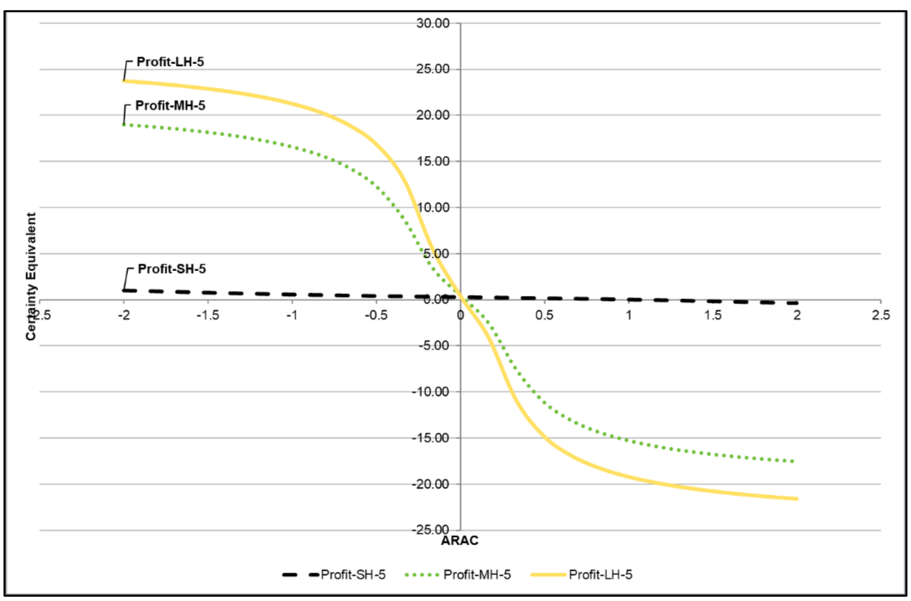

Figure 3.32 Stochastic Efficiency with Respect to a Function (SERF) Comparison for SH, MH and LH at 5% Profit Margin

Figure 3.33 shows a chart generated by SIMETAR through the SERF test comparing certainty equivalents across all aircraft at a ten percent profit margin. As we move from risk loving to risk averse, there is a shift from the preferred aircraft being the LH to the preferred aircraft being the SH. This occurs at the point of indifference where an applicator is indifferent to the associated risk.

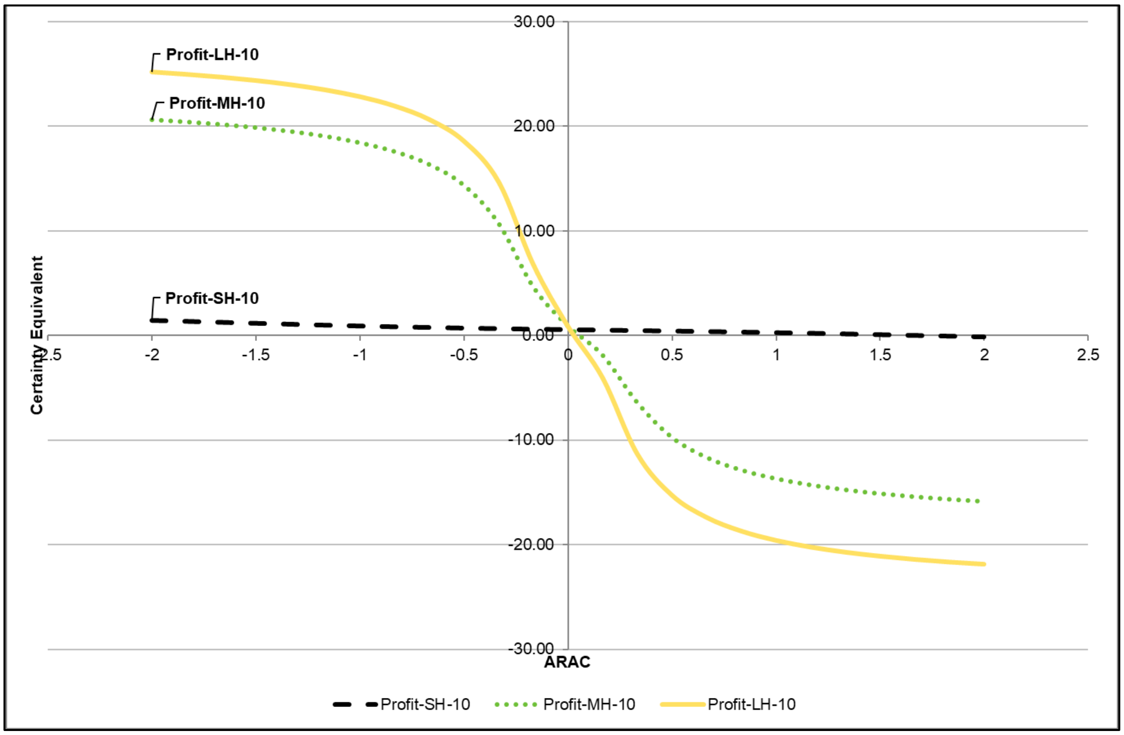

Figure 3.33 Stochastic Efficiency with Respect to a Function (SERF) Comparison for SH, MH and LH at 10% Profit Margin

Figure 3.34 shows a chart generated by SIMETAR through the SERF test comparing certainty equivalents across all aircraft at a fifteen percent profit margin. As we move from risk loving to risk averse, there is a shift from the preferred aircraft being the LH to the preferred aircraft being the SH. This occurs at the point of indifference where an applicator is indifferent to the associated risk.

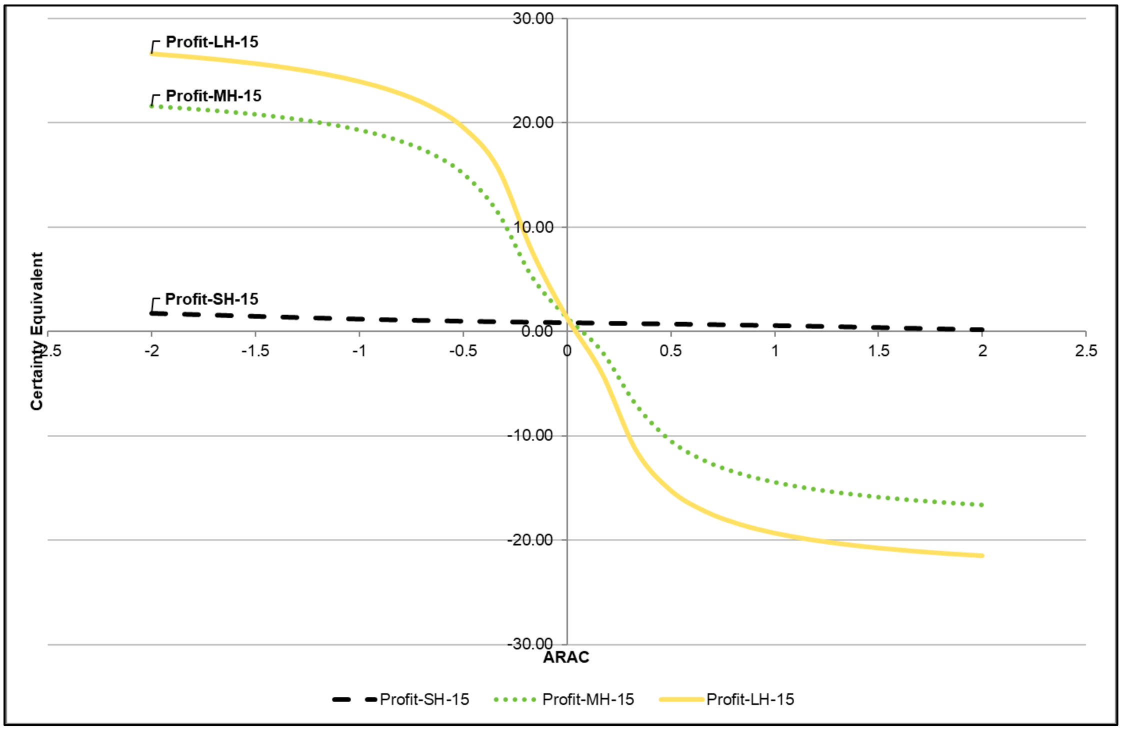

Figure 3.34 Stochastic Efficiency with Respect to a Function (SERF) Comparison for SH, MH and LH at 15% Profit Margin

Figure 3.35 shows a chart generated by SIMETAR through the SERF test comparing certainty equivalents across all aircraft at a twenty percent profit margin. As we move from risk loving to risk averse, there is a shift from the preferred aircraft being the LH to the preferred aircraft being the SH. This occurs at the point of indifference where an applicator is indifferent to the associated risk.

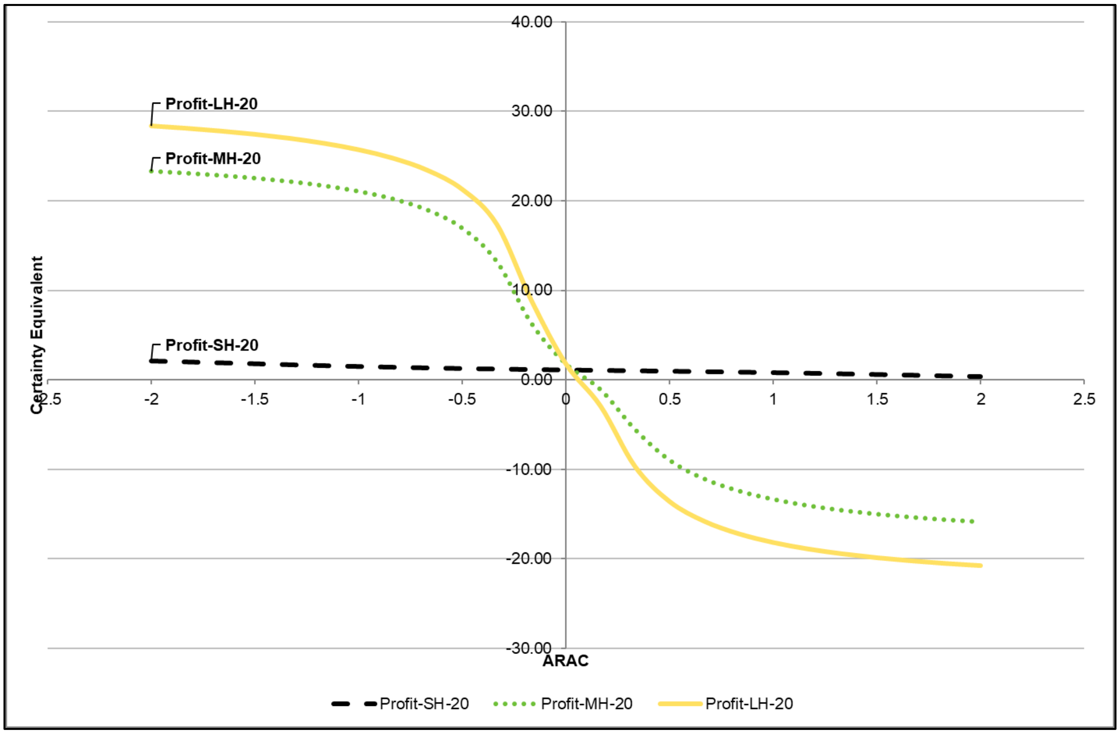

Figure 3.35 Stochastic Efficiency with Respect to a Function (SERF) Comparison for SH, MH and LH at 20% Profit Margin

3.5. Stop Light Chart Results

The Stop Light table summarizes the probabilities that the scenarios will be less than the lower target of (in red) and the probabilities that the risky alternatives will exceed a maximum target of (in green). The graphical display of probabilities of a risky alternative exceeding an upper target and falling below a lower target have proven a very powerful tool for helping decision makers rank risky alternatives (Richardson, 2008).

Figure 3.36 shows the probability for the SH, MH and LH aircraft having a profit per acre below -$0.405 in red, a profit per acre between -$0.405 and $0.967 in yellow and profit per acre above $0.967 in green under the 5% profit margin scenario. The SH aircraft has the highest probability (93%) for having a profit per acre above -$0.405, but also has the lowest probability (7%) for having a profit per acre above $0.967. Comparatively, the MH and LH aircraft have a higher probability (32% and 34%) than the SH aircraft of having a profit per acre below -$0.405, but both have a higher probability (37% and 37%) of having a profit per acre above $0.967. A risk-averse decision maker may choose to forgo the opportunity for higher profits for reduced risk of lower profits by using the SH aircraft. Conversely, a risk-loving decision maker may choose to purse the opportunity or higher profits despite the risk of lower profits by using the MH or LH aircraft.

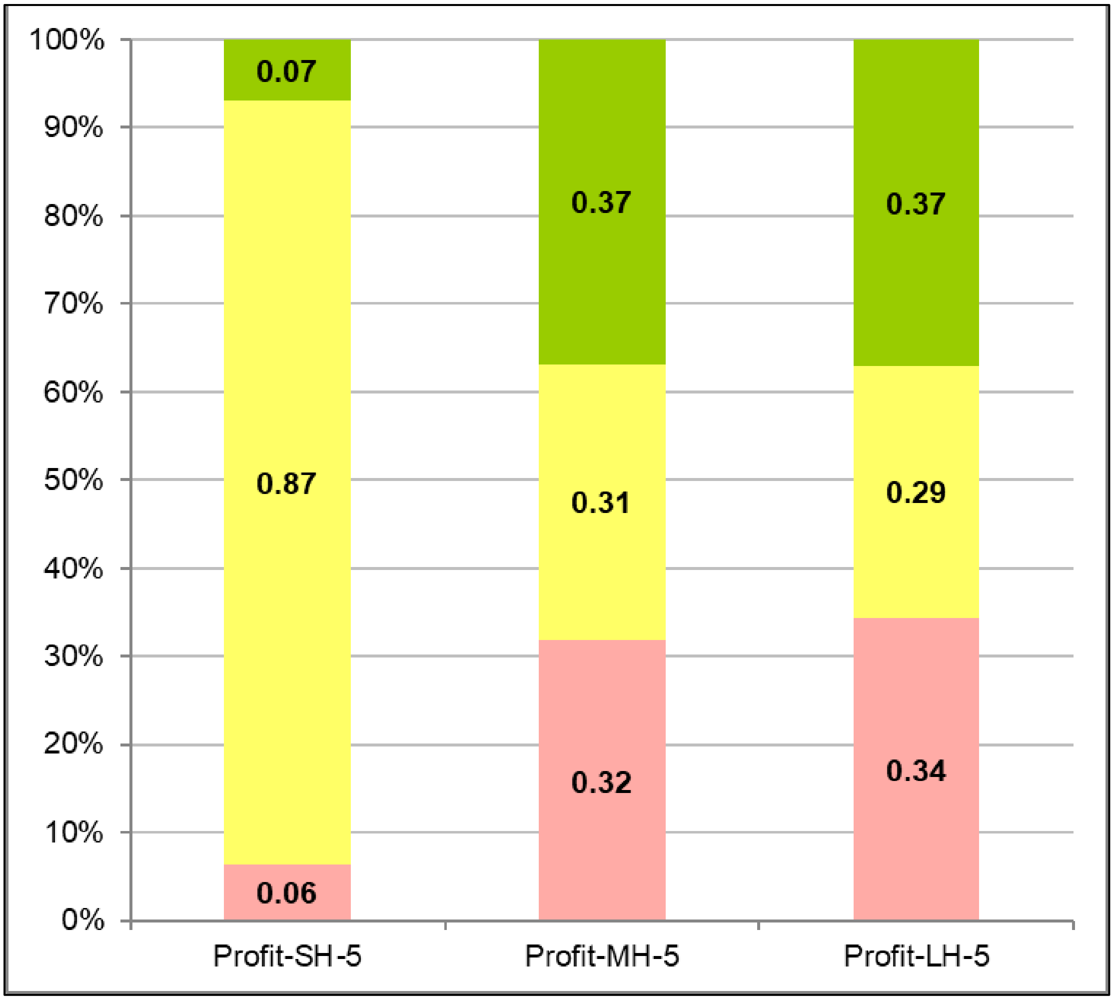

Figure 3.36 Stoplight Chart for Probabilities Less than -0.405 and Greater than 0.967 for SH, MH and LH at 5% Profit Margin

Figure 3.37 shows the probability for the SH, MH and LH aircraft having a profit per acre below -$0.170 in red, a profit per acre between -$0.170 and $1.292 in yellow and profit per acre above $1.292 in green under the 10% profit margin scenario. The SH aircraft has the highest probability (93%) for having a profit per acre above -$0.170, but also has the lowest probability (7%) for having a profit per acre above $1.292. Comparatively, the MH and LH aircraft have a higher probability (30% and 33%) than the SH aircraft of having a profit per acre below -$0.170, but both have a higher probability (37% and 37%) of having a profit per acre above $1.292.

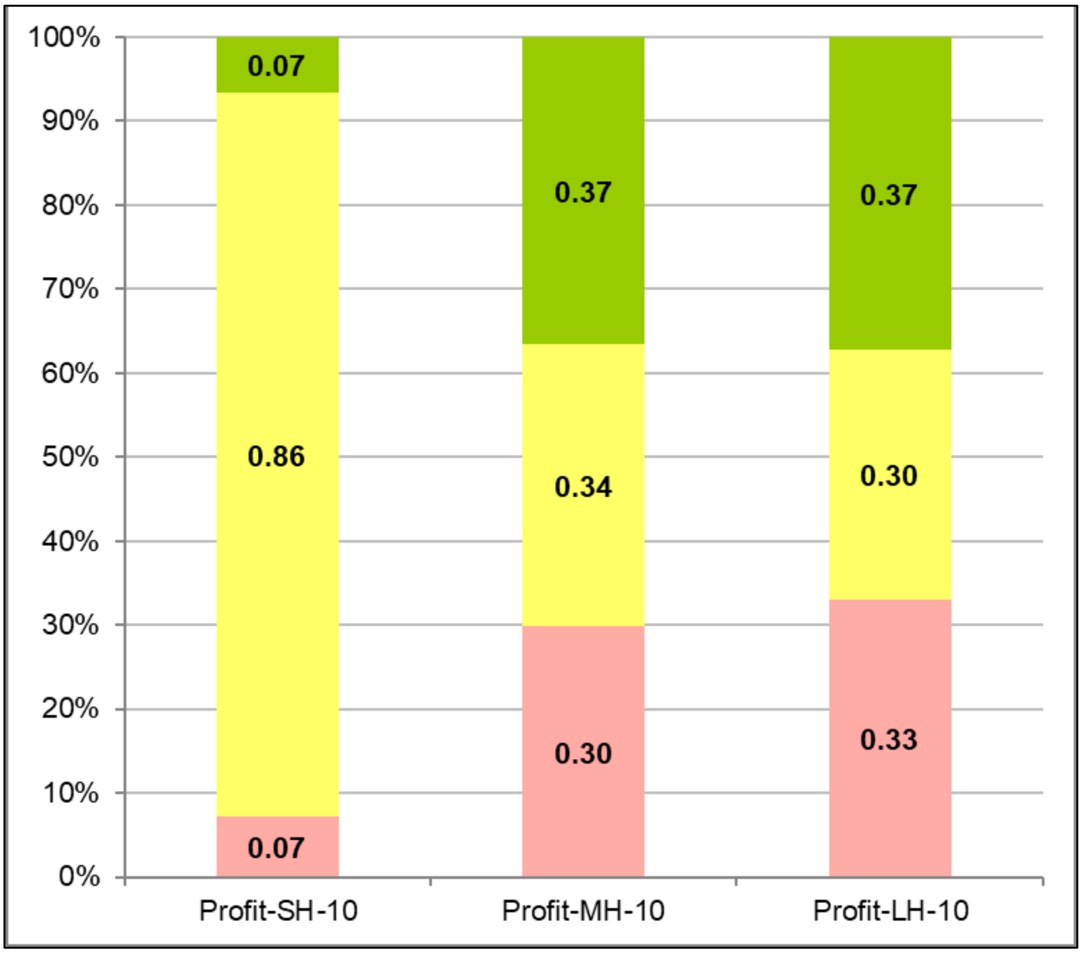

Figure 3.37 Stoplight Chart for Probabilities Less than -0.170 and Greater than 1.292 for SH, MH and LH at 10% Profit Margin

Figure 3.38 shows the probability for the SH, MH and LH aircraft having a profit per acre below $0.118 in red, a profit per acre between $0.118 and $1.564 in yellow and profit per acre above $1.564 in green under the 15% profit margin scenario. The SH aircraft has the highest probability (93%) for having a profit per acre above $0.118, but also has the lowest probability (7%) for having a profit per acre above $1.564. Comparatively, the MH and LH aircraft have a higher probability (28% and 30%) than the SH aircraft of having a profit per acre below $0.118, but both have a higher probability (38% and 40%) of having a profit per acre above $1.564.

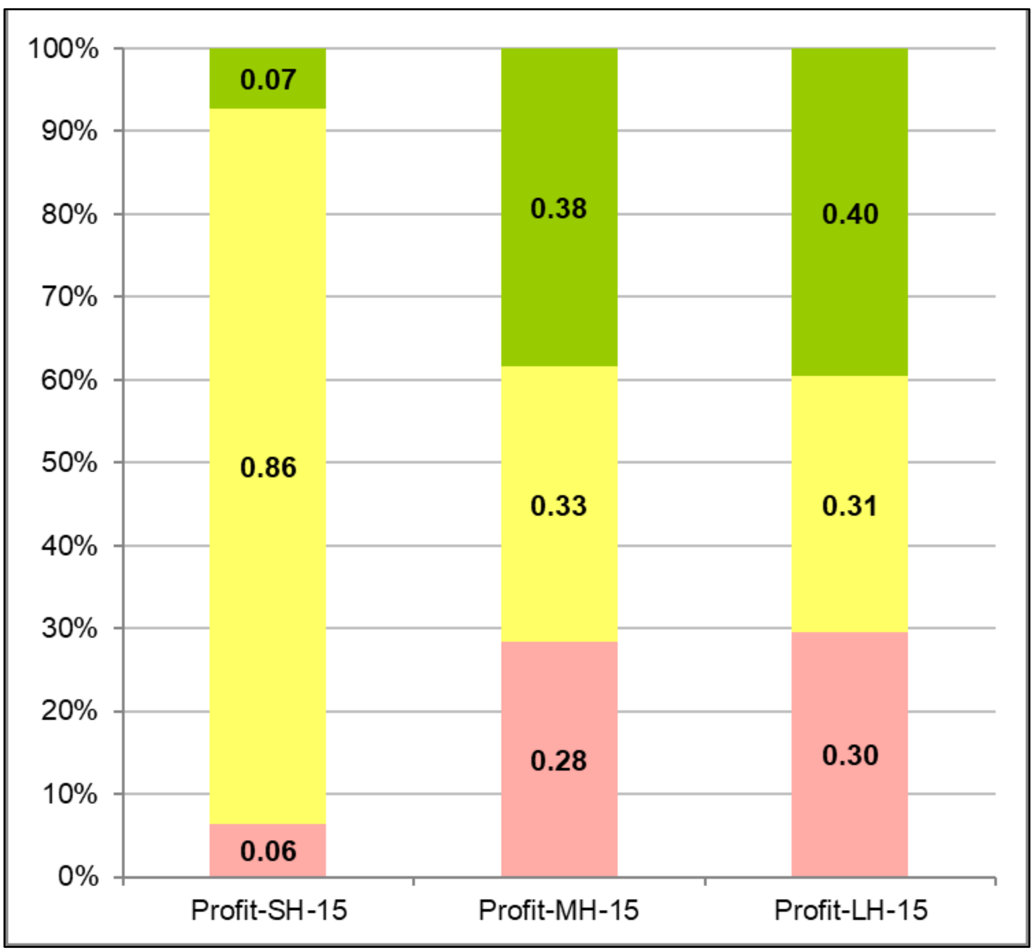

Figure 3.38 Stoplight Chart for Probabilities Less than 0.118 and Greater than 1.564 for SH, MH and LH at 15% Profit Margin

Figure 3.39 below shows the probability for the SH, MH and LH aircraft having a profit per acre below $0.382 in red, a profit per acre between $0.382 and $1.862 in yellow and profit per acre above $1.862 in green under the 20% profit margin scenario. The SH aircraft has the highest probability (93%) for having a profit per acre above $0.382, but also has the lowest probability (7%) for having a profit per acre above $1.862. Comparatively, the MH and LH aircraft have a higher probability (26% and 29%) than the SH aircraft of having a profit per acre below $0.382, but both have a higher probability (40% and 39%) of having a profit per acre above $1.862.

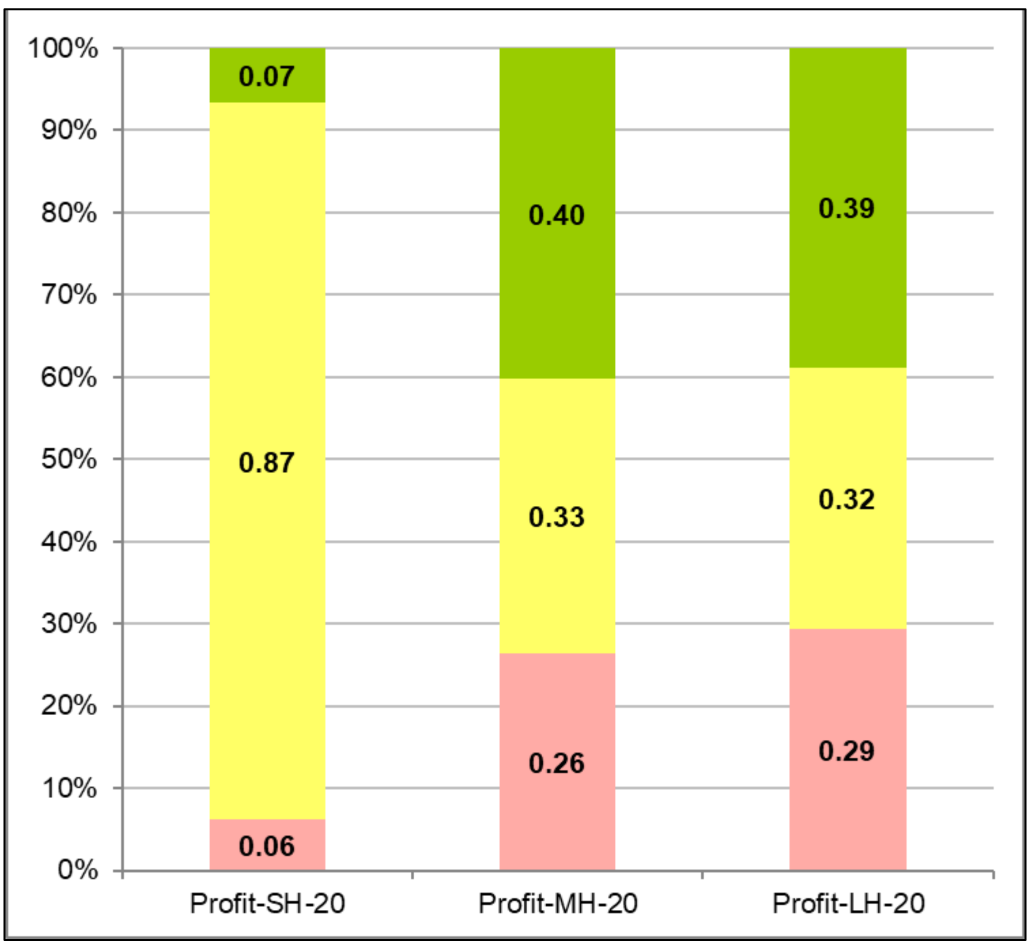

Figure 3.39 Stoplight Chart for Probabilities Less than 0.382 and Greater than 1.862 for SH, MH and LH at 20% Profit Margin

4. CONCLUSIONS

Understandably so, when comparing an aircraft against itself at each profit margin, profit per acre at five percent profit margin was less than ten percent profit margin which was less than fifteen percent profit margin which was less than twenty percent profit margin. Without looking at risk, to achieve a higher profit per acre, a higher profit margin must be put in place. However, when risk is introduced into the equation, we see a shift in preference.

The tests we have run allow us to evaluate the empirical distribution of profit per acre for spray jobs and determine the optimum profit per acre for those spray jobs at different predetermined profit margins of 5%, 10%, 15% and 20% for three different types of commonly used agricultural aircraft; SH, MH and LH. We see through the PDF and CDF graphs and output that profit per acre in clustered round the mean which demonstrates that the high profits per acre toward the upper quantile and low profits per acres toward the lower quantile are least observed and are less likely to be observed. Through the SDRF tests comparing an aircraft against itself at different profit margins, we observe that the higher profit margins are preferred to the lower profit margins, which is to be expected as they bring higher profits per acre. As we compare the aircraft against other aircraft at a given profit margin, we see a shift in preference. Across all profit margins, SH is preferred by the risk averse while the LH is preferred by the risk loving and preference for the MH aircraft is between the SH and LH aircraft.

In performing the tests, the ability arises to rank the most profitable spray application by aircraft type, based on predetermined risk aversion coefficients using cumulative distribution functions and stochastic dominance graphs. We see through the SERF test that at all targeted profit margins, the most risk averse individual down to the risk neutral individual will prefer to use the SH. Conversely, the most risk loving individual down to the risk neutral individual will prefer to use the LH. This is interesting, but also backs our assumption of how individuals operate in the real world. Aerial applicators operate in a risky industry and it is expected that they will try to mitigate risks where possible. However, each decision maker chooses what level of risk he or she is willing to accept. This is determined by economic decisions, but also largely by personal circumstances that have little to do with economics such as pilot confidence level, personal circumstances, etc. This is why in the real-world we see a wide variety of aircraft usage in the industry.

We see through the use of the simulation model developed in this study that risk impacts decision making. In the real-world of running any business, owners want to mitigate risk and aerial applicators are no different. While we have shown that here, there is room for further study in this area. For a given current revenue and profit stream for an aerial application business, we are in position to simulate revenue and profit for a future operation given the risk, so that the decision maker is strategically positioned to charge the best price to gain anticipated revenue and profit per acre. Now that this test simulation-risk model for one application business has been developed, it can be modified to fit the unique characteristics of nearly any other aerial application operation.

This will lead to the development of price, revenue and profit risk-simulation models for different aerial application businesses, by region, since cost and business practices associated with different regions within the United States could be considerably different, given the extent of the existing status of the industry. This geographic look at the industry was not discussed in this paper, but is a potential avenue for a further look into the industry that can be explored in a further study.

On a final note, the study findings are accurate, but more data is needed if we hope to drill down to truly precision pricing and targeted profit per acre. We had at our disposal for this study variable cost information, but lacked fixed cost information. Without this information, our results will be less accurate than they could be. In order to further this area of research, more data is needed. What we have shown here is the ability to conduct an in-depth study, but until we find partners willing to share in-depth records, this is extent to which we can advance.

REFERENCES

Dharmasena, S., G.C. Davis and O. Capps, Jr., 2014, "Partial versus General Equilibrium Calorie and Revenue Effects Associated with a Sugar-Sweetened Beverage Tax." Journal of Agricultural and Resource Economics, 39(2):157174

Greene, W., 2003, Econometric Analysis, 5th edition, Pearson Education, Inc., Upper Saddle River, New Jersey, USA

NAAA, 2016, National Agricultural Aviation Association, Voice of the Aerial Application Industry, Internet access: June 1, 2016

Richardson, J.W., K.D. Schumann, and P.A. Feldman, 2008, "SIMETAR, Simulation for Applied Risk Management."

Richardson, J.W., K.D. Schumann, and P.A. Feldman, 2004, "SIMETAR Simulation for Applied Risk Management, Technical Guide for Simetar."