SELF-PROPELLED FORAGE HARVESTER SALES ANALYSIS

by

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B.S., North Dakota State University, 1997

A THESIS

Submitted in partial fulfillment of the requirements

for the degree

MASTER OF AGRIBUSINESS

Department of Agricultural Economics

College of Agriculture

KANSAS STATE UNIVERSITY

Manhattan, Kansas

2015

Approved by:

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ABSTRACT

Self-propelled forage harvesters are used to make feed for livestock. Producers prefer forage made with these machines because they are able to deliver a feed value that enables improved productivity of their animals in terms of milk production for dairy animals and weight gain for beef animals. Self-propelled forage harvesters are able to make a variety of feed from different crops, including whole-plant corn silage, earlage, and haylage, among others. The self-propelled forage harvester is a complex and expensive piece of machinery for a producer to own.

The self-propelled forage harvester market in the United States is a growing market, but small when compared to other equipment such as combines. In today's environment, productivity is crucial to the success of the agricultural producer. Self-propelled forage harvesters are no exception. Growth of the self-propelled forage harvester market is reflected in increased unit sales, total horsepower sold, and average horsepower of the self-propelled forage harvesters sold in the United States. This study looks at changes in the number and size of self-propelled forage harvesters being purchased and what factors might be driving those changes.

This study found that the amount of milk produced, the type of customer purchasing the equipment, and the average price of milk a producer received explained 81.2% of the variation in the number of self-propelled forage harvesters sold from 2000-2014. Study results also show that the size of dairy operation, the type of customer purchasing the equipment, and the average price of milk explained 88% of the variability in total horsepower of self-propelled forage harvesters sold from 2000-2014. Finally, the size

of dairy operation that a typical cow comes from, the type of customer purchasing the equipment, and the average price of corn were able to explain 98% of the variation of average horsepower of self-propelled forage harvesters over that same time period.

The model and analysis will be shared with product planners from John Deere as they develop new machine specifications for self-propelled forage harvesters in the future.

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ACKNOWLEDGEMENTS

The author wishes to first acknowledge the staff and faculty at Kansas State University's Master of Agribusiness (MAB) program for their dedication in delivering a fantastic distance program. I would also to thank Dr. Kevin Dhuyvetter for his involvement in overseeing this thesis process as major professor. His tireless efforts and analytical insights were key to finishing this thesis. I would also like to recognize Dr. Sean Fox and Dr. Mykel Taylor for their time and feedback as committee members on this thesis project. Thank you to Mary Bowen and Deborah Kohl for their encouragement and support throughout the entire program.

I wish to thank my classmates in this cohort. Their energy, enthusiasm and willingness to share their talents really made this experience special.

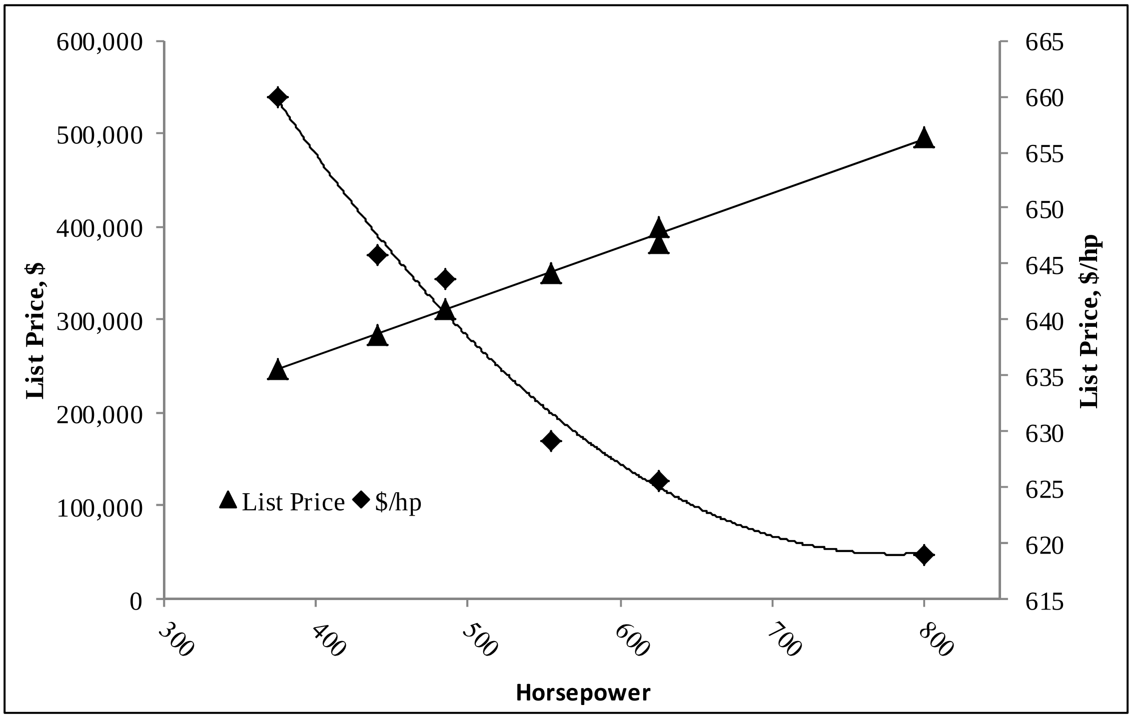
Finally, I wish to thank my loving family at home: Adrienne, Ashton, and Gentry. Their encouragement, support, and sacrifice throughout the entire MAB experience has made this degree worthwhile. Going through the program may not have made me a better father, but it did help me grow and learn to think more critically. Together we share this success. Thank you for your unwavering patience.

CHAPTER I: INTRODUCTION

1.1 North American Self-Propelled Forage Harvester Market

The North American self-propelled forage harvester market is not very large when compared to the total harvesting equipment market segment. According Ag Equipment Manufacturers (AEM), 2013 sales of new self-propelled forage harvesters were at an all-time high (752). To put that in perspective, 2013 sales of new combines totaled approximately 13,000 units (Association of Equipment Manufacturers 2014). The self-propelled forage harvester market could be considered a niche market due to the specialization and cost of the machines. The list price of a new self-propelled forage harvester can range from $260,000 for a smaller machine to $500,000 plus for a larger machine. This makes a self-propelled forage harvester one the most expensive pieces of equipment a producer may own. Figure 1.1 identifies list price of machines of different sizes ranging from 400 hp to 800 hp (John Deere Sales Brochure) (John Deere Configurator). It is clear that the larger machines require more capital, however, the investment price per unit of horsepower declines as the machines get larger. Thus if there is an opportunity to fully use the horsepower of the larger machines, the cost of operating the larger machine per unit of output may actually decrease.

Figure 1.1: Self-Propelled Forage Harvester List Price by Horsepower.



The four manufacturers that sell and support self-propelled forage harvesters in the United States are John Deere, Claas, Krone, and New Holland. Due to the small market and the limited number of competitors, it is critical to fully understand the market and deliver the product producers demand.

Self-propelled forage harvester manufacturers face the challenge of building machines with enough productivity to meet the requirements of the customers, while not overproducing machines and negatively impacting their profitability. Over a period of the last 10 years, there has been an upward trend in the number of self-propelled forage harvesters sold, as well as an increase in the horsepower of those units.

Horsepower is a term used to describe the power of an engine. For the purposes of this thesis, horsepower is a proxy for productivity of the self-propelled forage harvester. For example, more capacity is required to harvest corn than hay due to higher volumes and a more difficult crop to process. In addition, many producers prefer to use a kernel processor in their self-propelled forage harvester when chopping corn silage. A kernel processor is a secondary step that “scuffs” the corn kernels tough outer shell, resulting in better nutritional utilization by livestock when they eat the corn silage. However, this further processing requires the self-propelled forage harvester to have more horsepower than it does without the kernel processor. Thus, as a general rule, producers or custom operators harvesting corn silage will need more horsepower, or capacity, than those harvesting haylage, while those using kernel processors for corn silage will need more power yet.

AEM is an organization that collects monthly equipment sales reports from member manufacturers. AEM is then able to provide manufacturers with an aggregate total of the sales from the reporting manufacturers. Individual manufacturers know their own sales and can calculate market share given the total industry sales that AEM provides. Since 2000, the self-propelled forage harvester industry has increased sales over 35%. At the same time, the average horsepower of the self-propelled forage harvesters have increased by nearly 30% (Figure 1.2). By increasing the number of machines sold and the average horsepower of those machines, the total horsepower capacity introduced each year has increased by nearly 75% since 2000 (Table 1.1).

Figure 1.2: Industry Sales and Average Horsepower of Self-Propelled Forage Harvesters, Ag Equipment Manufacturers, 2000-2014.

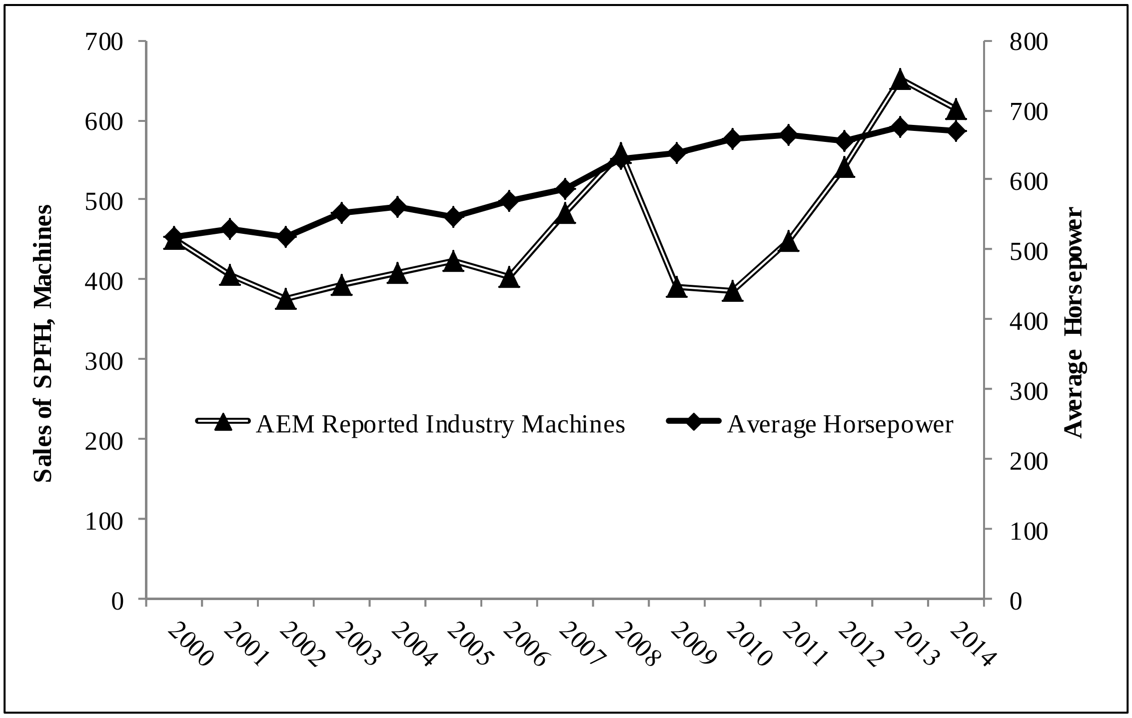


Table 1.1: New Machine Sales, Average Horsepower and Total Horsepower, Ag Equipment Manufacturers, 2000-2014.

Year	Machines	Average HP	Total HP
2000	450	520	233,820
2001	407	530	215,873
2002	377	520	195,927
2003	393	553	217,250
2004	409	562	229,817
2005	423	547	231,339
2006	404	569	229,836
2007	483	586	282,990
2008	558	630	351,652
2009	390	638	248,742
2010	387	659	254,840
2011	449	663	297,822
2012	542	657	356,094
2013	652	675	439,774
2014	613	670	410,587

1.2 Customers

There are two main types of self-propelled forage harvester customers. The first is the livestock producer (usually a beef feedlot or dairy operator) who owns a self-propelled forage harvester and produces forage for their livestock operation. The producers can be further segmented based on gross farm revenue generated by their operation. The demographic information may be a useful tool to help determine the drive to higher horsepower. This thesis looks at three producer segments: 1) Non-commercial agricultural producers generating between $1 and $250,000 gross farm revenue per year; 2) Commercial agricultural producers generating over $250,000 annual gross farm revenue; and 3) Agricultural service providers who perform custom work for livestock producers. As a point of clarification, agricultural service providers may harvest some forage for themselves as well as for others. However, the majority of their revenue is generated by custom harvesting for other livestock producers.

It is important to distinguish between the types of customers because their needs can be considerably different. An agricultural service provider typically is paid based on the tons of forage harvested, therefore, the more productive they are, the more revenue they can potentially generate. A livestock producer gets paid when they either sell the livestock (in the case of a feedlot) or when they sell the milk (in the case of a dairy). Therefore they potentially have different motives for their purchasing behaviors. If agricultural service providers focus on productivity because of how they generate revenue, they likely will demand high capacity harvesters. On the other hand, livestock producers who use self-propelled forage harvester to produce an input to their operations that eventually leads to revenue generation may be less concerned about in-field productivity. Thus, it is important to consider the type of buyers as that will potentially impact what types of machines (size) are being purchased.

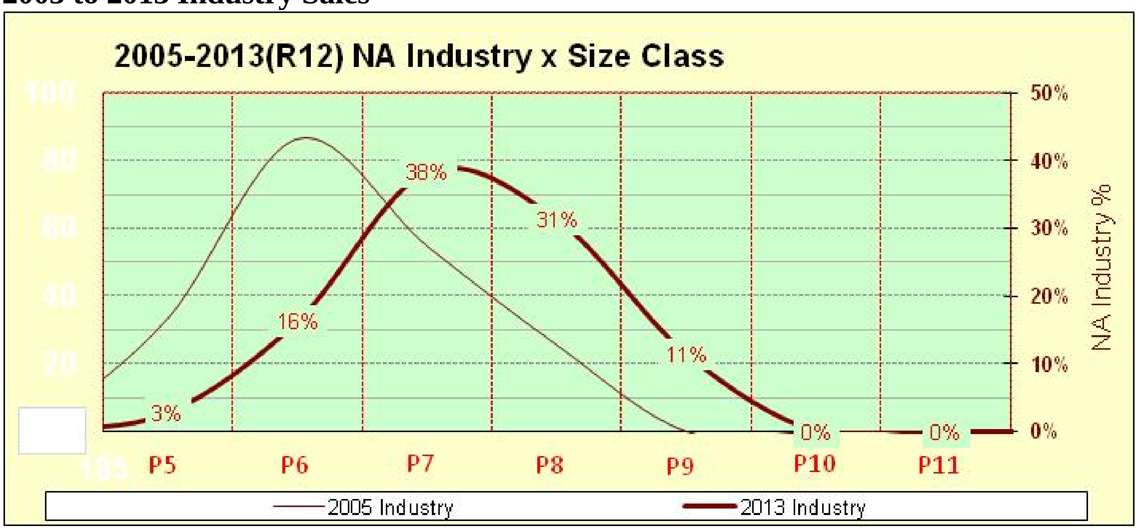
Customer information comes from Uniform Commercial Code (UCC-1) filings that are submitted when a borrower claims personal property as collateral against a loan (InvestorWords n.d.). The UCC-1 customer data are filtered through several databases to determine which customer segment they belong to – Non-commercial Ag, Commercial Ag, or Ag Service Provider (Beisner 2014).

1.3 Objective

The objective of this thesis is to develop statistical models to explain the upward trend in horsepower of self-propelled forage harvesters being purchased in the United States. This research will be presented to the Hay & Forage product and market planning teams at John Deere Company to help with future self-propelled forage harvester product development programs. Being able to more accurately predict the capacity growth of self-propelled forage harvesters will enable the company to make better investment decisions in machine function, form, and size. There is considerable risk when designing a new machine. The company does not want the machine to be too large, causing them to be overpriced for the market. Conversely, if the machines are too small, customers may choose other companies' products and sales will be low. Having a data-driven process to support anecdotal customer feedback is useful in long-term decision making.

An example of how this type of information is used exists at John Deere Harvester Works. A combine "snow drift" model has been developed showing the change in combine power groups over time is displayed in Figure 1.3. The term snow drift is used because the visual of a time series chart of the distribution of power size resembles that of a snow drift. An example of this snow drift for combines is depicted in Figure 1.3. The power groups listed on the x-axis are an industry classification of the relative capacity of the combines. This classification is unique to combines as no other equipment is segmented this way. The y-axis is the percent of sales in North America. The thin line in the graph is the sales distribution in 2005 and the thick line in the graph is the sales distribution in 2013. It can be seen that there has been a shift to larger capacity combines over time (the 2013 distribution is to the right of the 2005 distribution.) The distributions both show a "drift" toward larger capacity combines, even though the majority in the industry may be smaller (i.e., the distribution tends to be skewed to the right). The objective of this thesis is to look at similar data for self-propelled forage harvesters to identify factors that might lead to changing customer purchase decisions over time.

Figure 1.3: Example of Snow Drift Model for Combine Power Groups comparing 2005 to 2013 Industry Sales

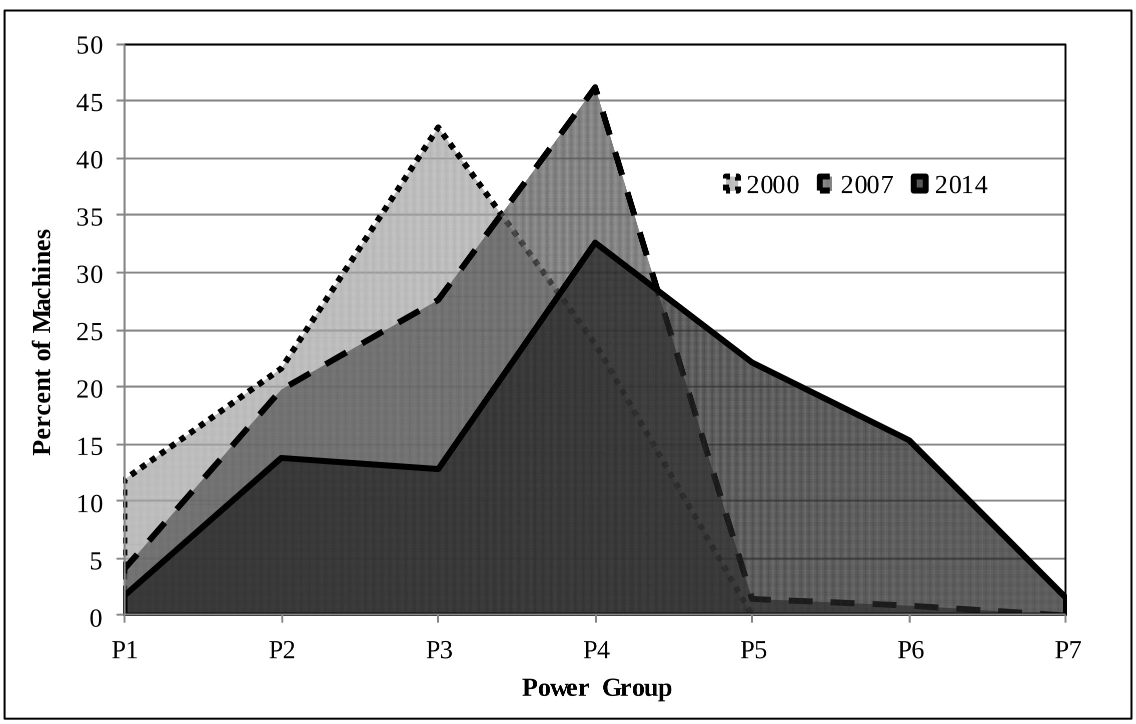


As previously stated, combines are the only equipment that have an industry classification of power group rating. For this thesis, self-propelled forage harvesters have been categorized into power group ratings. Table 1.2 shows the breakdown of the power groups by horsepower class and the total number self-propelled forage harvesters sold in each power group from 2000-2014. Figure 1.4 depicts a view of the shift in power group over time similar to that of the combine snow drift model.

Table 1.3: Self-propelled forage harvester power group ratings and Units Sold, 2000-2014.

Power Group	Minimum HP	Maximum HP	Total Machines
P1	251	400	318
P2	401	500	786
P3	501	600	1,133
P4	601	700	1,804
P5	701	800	425
P6	801	900	412
P7	901	1100	56

Figure 1.4: Industry Shift in Power Group of Self-Propelled Forage Harvesters, 2000-2014.



CHAPTER II: LITERATURE REVIEW

There has been little research completed on the topic of self-propelled forage harvesters in terms of horsepower and productivity growth. However, there has been significant research completed on forage harvesting systems capacity. Forage harvesting systems capacity is looks at the entire harvesting system including the forage harvester, transport vehicles (trucks or wagons pulled by tractors), and the storage of the forage (silos, baggers, or silage pits). Some sort of mechanical power (PTO-driven baggers, blowers, or tractors utilized for packing the pits) is required to move forage from the transport vehicles to the storage location. A secondary vein of similar capacity utilization research has looked at the impact of field shape, slope, and crop yield on the harvesting process and the productivity of the harvester.

Research indirectly related to forage harvester horsepower growth includes machinery cost estimates. As machines get larger, not only does the initial purchase price increase, but so does the operating cost. The economic engineering approach that economists use to estimate farm machinery operating costs is sometimes called the DIRTI-5 approach, which stands for the main cost components of Depreciation, Interest, Repairs, Taxes, and Insurance (Lazarus 2008).

2.1 Systems Approach to Forage Harvest Productivity

Matching equipment size and need to the number of acres harvested has a direct impact on the costs of making hay and silage (Buckmaster 2006). Harvesting machinery, and the associated labor cost, is often the single largest contributor to the cost of producing and delivering forages. Because of this, selection and sizing of equipment is important (Purdue University Extension 2008). Buckmaster (2006) developed a spreadsheet that automates the use of a manually-drawn cycle diagram to identify the proper sizing of the equipment needs in a forage harvesting system. Forage harvester capacity is used as the basis for sizing other equipment and power units for the system. The other power equipment and power units would be at the receiving end of the system where the forage will be stored in bunks, bags, or silos. Using cycle analysis, the needs for transportation are determined to keep the harvester running at full capacity (Buckmaster 2006). Buckmaster's spreadsheet allows the owner/operator to ensure the entire harvesting system can be utilized at full capacity.

Buckmaster identified how to determine forage harvester capacity based on the horsepower rating of the harvester and a calculation that depends upon the crop being harvested. Forage harvester capacity is impacted by four limiting factors: power, throughput capacity, speed, and traction. Of these four, he claims that power and throughput capacity have the greatest impact in most crop situations. A study completed in Spain found the crop yield has a major impact on effective harvest capacity – as crop yields increase, effective harvest capacity decreases (Amiama C. 2008). This study reinforces the importance of throughput capacity, consistent with Buckmaster's findings. The study also found that the shape and size of the field has an impact on optimal capacity. The longer the fields, the more efficient the forage harvester can be as there are fewer turns (less operation out of crop).

Buckmaster also identified how to calculate the capacity into storage at the unloading site based on the type of unloading system. Silo blowers, silo baggers, and packers all have different capacity constraints, typically dependent upon the horsepower requirements and how effective the systems are at reaching rated capacity. As long as the forage harvester in the field and the equipment at the other end are matched properly, a producer can add or subtract transport vehicles to keep the system running at full capacity. Buckmaster's approach helps the producer determine how many transport vehicles are needed based upon speed, capacity, crop, and distance from field to storage. Simulations with these factors considered, generated a simple equation that projects the number and size of transporters required to keep a forage harvester fully utilized (Purdue University Extension 2008). The importance of running the entire system at full capacity cannot be overstated. As noted earlier, the cost of the harvesting equipment and the labor to run that equipment is typically the highest of the entire operation. To have the harvest equipment sit idle for any length of time, due to any circumstance, but especially due to system limitations, is costly. On the other hand, not completing the harvest in a timely manner can lead to lower quality forages, which can also be extremely costly. Thus, the challenge for producers is to identify the size of harvesting equipment such that harvest can occur in a timely fashion without equipment sitting idle.

2.2 Bigger Is Not Always Better

There is a thought that producers want larger equipment to be more productive and make more money. That can happen in some, but not all, cases. In conducting the literature review, several examples surfaced where bigger machines reduced profits of the producer. One situation is custom harvesters who charge by the hour rather than by the ton. Tim Meister, Division Marketing Manager for John Deere, walks through an example where a custom harvester can make less money with a larger forage harvester than with a smaller one (Holin 2010). Consider the following example, a 500 horsepower harvester can chop 200 tons/hour and the rate charged is $400/hour, plus fuel costs of $40/hour (based on $2/gallon price) averaging $2.20/ton in revenue. A 600 horsepower harvester can chop 250 tons/hour for $475/hour plus $50/hour for fuel, totaling $525/hour but generating only $2.10/ton in revenue; a loss of $0.10/ton which is about $5,000 for 2,000 acres. To ensure profitability remains the same, the custom harvester should factor productivity increases into the rates charged for harvesting, along with the potential increase in fuel use for the larger horsepower machine.

There are several other factors that come into play when considering purchasing a higher horsepower machine including: fuel usage, increased carrying cost (financing a larger payment for a more expensive machine), trade-in value, and logistical capacity. If the larger machine is sitting idle due to a lack of transport capacity or storage capacity, the loss of efficiency is quite costly.

Another way to look at the issue is to consider the operating cost for the equipment and the cost of increasing in size. Machine costs can be separated into time-related costs and use-related costs (W. F. Lazarus 2014). The use-related costs occur only when a machine is used and include fuel, lubrication, use-related repairs, and labor. Time-related costs included interest, insurance, personal property taxes, and housing. Depreciation is both a use- and time-related cost. Lazarus developed formulas to determine the time-related (overhead) costs per year. Variables that increase costs when moving to larger equipment include depreciation and use-related costs. Repairs increase due to the increase in the size and the amount of parts used in larger machines versus smaller machines. Fuel usage, lubricants, etc. will also increase as the machine gets larger. According to Lazarus, a 315 horsepower self-propelled forage harvester is estimated to cost about$120/hour of use for 300 hours of annual usage compared to a 625 horsepower self-propelled forage harvester at $201/hour of use for 300 hours of annual usage. It is important to recognize that in those 300 hours of usage, the 625 horsepower self-propelled forage harvester should be able to do more work, but it is tied back to the previous discussion about total harvest system efficiencies. To fully utilize the harvest capacity of the forage harvester, it is important to have a complete system supporting that capacity. In other words, the impact on costs will depend upon machine use, thus the 625 horsepower machine might actually have a lower cost per ton of forage harvested if it is used efficiently.

For the purpose of this thesis it is assumed that when customers purchase machines they have systems to support the harvesting capacity purchased. That is, the harvest system is not a limiting factor for horsepower growth.

CHAPTER III DATA AND METHODS

3.1 Data

As mentioned previously, there has not been much research conducted in the area of self-propelled forage harvester sales or horsepower growth. To gain an understanding of what could be driving the observed upward trend in growth, a variety of data were gathered.

Industry sales information from 2000-2014 was acquired from the John Deere Enterprise Market Research group. The raw data are UCC-1 filings on equipment purchases. This information includes customer information (name, business name, and address), manufacturer, and model numbers, as well as the loan amount. Research on the internet provided the horsepower rating for individual models for each of the manufacturers. This information allowed for the calculation of the average horsepower of all the self-propelled forage harvesters as well as the total horsepower available per year (sum of all the machines multiplied by their horsepower).

Self-propelled forage harvesters are used to produce forage for the livestock industry. For the purpose of this thesis, feedlot and dairy data related to number and size of operations in the United States were analyzed to determine if there was an impact on forage harvester sales and horsepower.

Survey data from NASS show the number of dairy operations are decreasing and the number of milk-producing dairy cattle is staying relatively constant (Figure 3.1). The number of larger dairies, measured in terms of 500 plus head, has been increasing slightly over time (Figure 3.2).[1]

[1] There are instances where the NASS data were incomplete. A calculation was made using linear analysis to fill in the missing information.

Figure 3.1: Total Dairy Operations and Total Dairy Cows, NASS, 2000-2014.

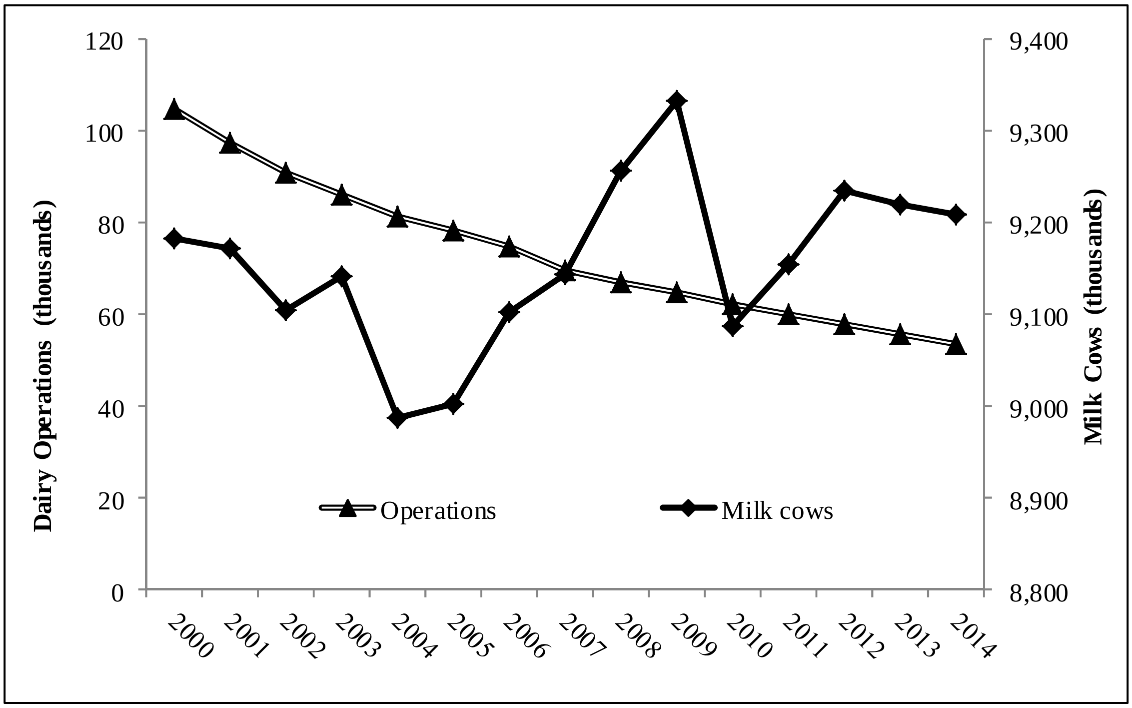
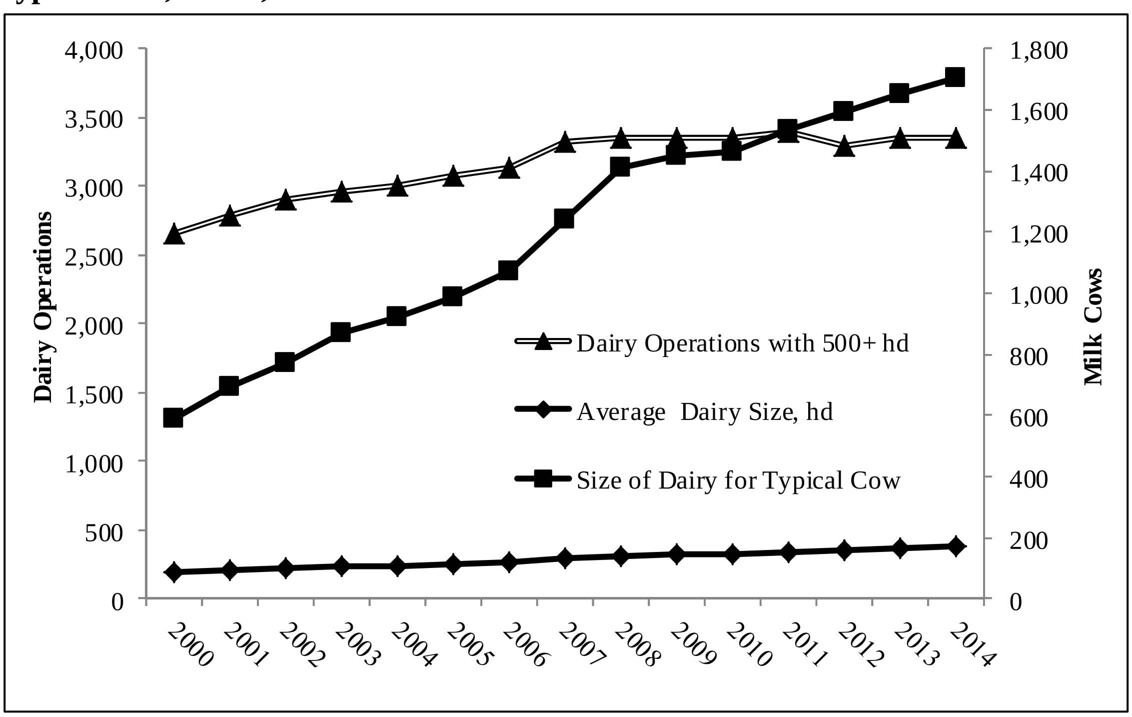


Figure 3.2: 500 Plus Head Dairy Operations, Average Dairy Size and Size of Dairy for Typical Cow, NASS, 2000-2014.



Because the dairy herd has remained relatively constant while the total operations has been declining this suggests that the average dairy size is increasing. Furthermore, because the number of large dairies has been constant (or increasing), this indicates that large dairies are getting larger. A dairy operation of 500 head or greater is the variable representing the larger dairies. The NASS data show that dairy operations have been declining at a compound annual growth rate of -4.4% per year since 2000. But dairy operations of 500 head or greater have grown at CAGR of 1.3% per year over this same time period. This correlates with the increase in milk production at a compound annual growth rate of 1.4% per year since 2000. The total dairy cow herd has remained relatively flat since 2000 at a compound annual growth rate of 0.02% (Table 3.1).

Table 3.1: Compound Annual Growth Rate of Number of Total Dairy Operations, 500 plus Head Dairy Operations, Total Dairy Cow Inventory, Total Milk Production, NASS, 2000-2014.

Year	Total Dairy Operations	500 plus Head Operations	Total Dairy Cows (000's)	Total Milk Production (million pounds)
2000	105,065	2,660	9,183	167,393
2001	97,460	2,795	9,172	165,332
2002	91,240	2,910	9,106	170,063
2003	86,360	2,965	9,142	170,348
2004	81,520	3,010	8,988	170,832
2005	78,300	3,073	9,004	176,931
2006	74,880	3,133	9,104	181,782
2007	69,995	3,320	9,145	185,654
2008	67,000	3,350	9,257	189,978
2009	65,000	3,350	9,333	189,202
2010	62,500	3,350	9,087	192,877
2011	60,000	3,400	9,156	196,255
2012	58,000	3,300	9,236	200,642
2013	55,667	3,350	9,221	201,218
2014	53,556	3,350	9,209	206,300
CAGR	-4.4%	1.5%	0.02%	1.4%

The NASS data also show that as the dairy operations are getting larger over time, the cattle on those operations are more productive in terms of milk produced per cow than on smaller dairies (data not shown). To help capture the effect of consolidation in the dairy industry, two variables were created: the size of dairy for a typical cow and the size of dairy for a typical hundredweight (cwt) of milk production. The size of dairy for a typical cow is defined as a volume-weighted measure that accounts for an increasing population of the dairy herd in larger dairies. Specifically, it is calculated as the average dairy size (number of cows divided by number of farms) for each size category (e.g., 1-29, 30-49, 50-99, etc.) times the percent of total cows in the industry for each size category. The typical cwt was calculated in the same way, using milk production in the calculations rather than cows. This is different than the average size of a dairy because of the sheer number of smaller dairies. Large operations (500 plus head) only make up 6% of the total dairy operations, but they represent 64% of the production and 60% of the dairy cows in 2014. While the size of dairy for a typical cow and typical cwt of milk follow a similar pattern, the size for a typical cwt is larger; this further supports the increase in productivity for the larger dairies (Table 3.2).

The average milk price per hundredweight was also considered as a possible factor impacting silage harvester purchases. As the price of milk received by the producer increases, their revenue will increase as well; the impact on self-propelled forage harvesters could be potentially two-fold: 1) at higher milk prices, they are generating more revenue and potentially profit, therefore they can afford larger machines, and 2) at higher milk prices the benefit of having higher quality forage (due to increased harvest timeliness) is higher. Milk prices at a national level were gathered on an annual basis from the NASS database.

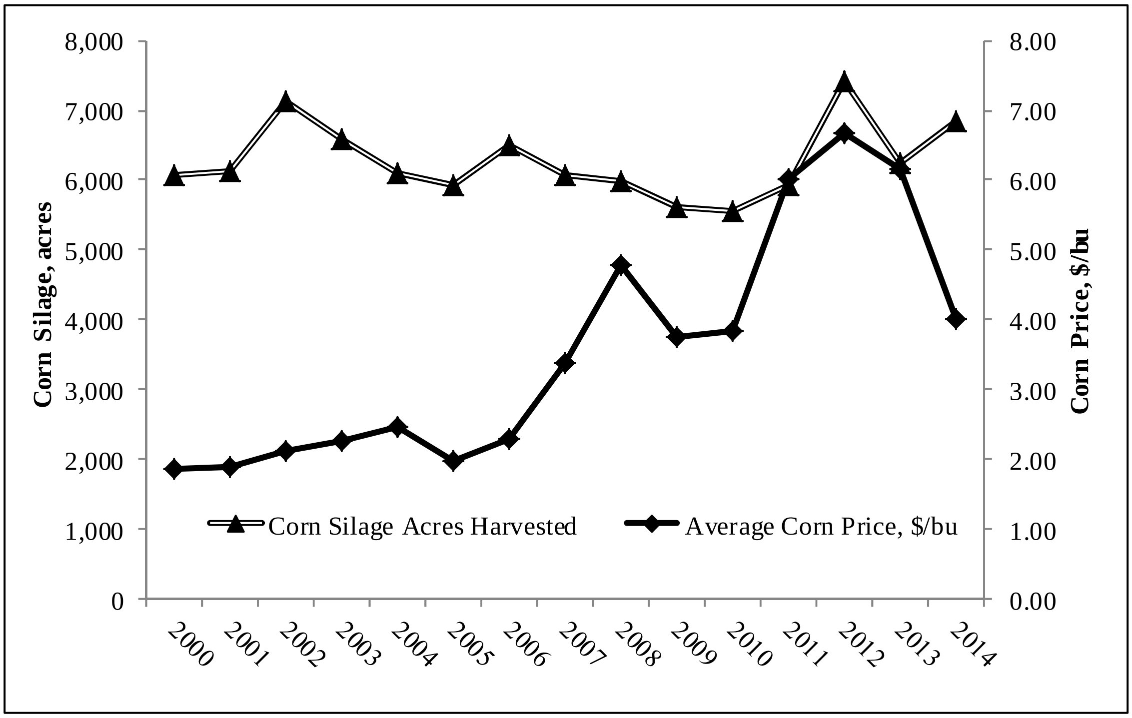
Data for beef feedlots were also gathered for consideration in estimating the model for average horsepower. As the number of large feedlots increases, the need for larger horsepower self-propelled forage harvesters would increase as well. The data show that as a percentage of the total feedlots, those with a capacity of 1,000 head or more have increased slightly; however the actual number of feedlots has declined slightly. The total number of feedlots has declined by a compound annual growth rate of -2.06% from 2000 to 2014. Similar to the dairy consolidation measures, several feedlot industry measures were used, one based on cattle on feed (January 1 survey data) and another based the annual marketings of feedlots in the United States. That is, feedlot size was defined either based on cattle on feed and/or based on marketings. These two variables show a steady, but slow growth in the size of the feedlots as well (Table 3.2).

Table 3.2: Size of Dairy Operation for Typical Cow and Typical Hundredweight of Milk and Cattle on Feed and Marketings from a Typical Feedlot, 2000-2014.

	Size of Dairy (head)		January 1 Cattle on Feed from a Typical Feedlot	Marketings from a Typical Feedlot
Year	Typical Cow	Typical cwt		
2000	590	663	52,536	21,075
2001	695	779	53,463	23,476
2002	772	857	52,885	23,197
2003	868	954	52,698	20,020
2004	920	1,001	50,696	22,471
2005	986	1,085	49,230	22,543
2006	1,076	1,168	49,325	23,524
2007	1,244	1,364	48,683	23,816
2008	1,414	1,490	49,590	24,390
2009	1,452	1,536	48,617	21,790
2010	1,462	1,558	49,644	20,595
2011	1,535	1,638	51,279	22,732
2012	1,596	1,704	51,973	26,170
2013	1,652	1,765	55,563	25,156
2014	1,703	1,819	50,736	25,089

Corn silage acres harvested annually as well as the average corn prices received were also considered as potential inputs to the model. As corn acres harvested for silage changed, would that have an impact on self-propelled forage harvester horsepower requirements? The data show corn acres harvested for silage have been erratic from 2000-2014 (Figure 3.3). Average corn price received was considered as another variable for the model. As the price of corn increases, so does the value of corn silage. Dairies have an inelastic demand for corn sileage, therefore as the corn sileage price increases, the need to minimize waste and maximize quality will be the approach to managing around the high prices. This increases the need for a more timely harvest, potentially leading to larger self-propelled forage harvesters. Figure 3.3 shows that corn price was relatively stable from 2000 to 2006, then steadily increased to 2013. The price in 2014 has declined back to 2010 levels, but still remains higher than it did in the early 2000's (Figure 3.3).

Figure 3.3: Acres of Corn Harvested for Silage and Average Price per Bushel of Corn, NASS, 2000-2014.



The final variables that are considered for estimating the model include the customer segmentation information discussed in section 1.2. These data are from John Deere Enterprise Market Research and describe customer segmentation by gross farm revenue or by agricultural service provider. The data show that commercial agricultural purchasers of self-propelled forage harvesters have increased over time, which also follows the trends of the size of dairy and feedlot operations. Non-commercial agricultural purchasers and agricultural service provider purchasers of self-propelled forage harvesters have been decreasing the last 15 years (Figure 3.4).

Figure 3.4: Percentage of Customer Segments Purchasers of Self-Propelled Forage Harvester, 2000-2014

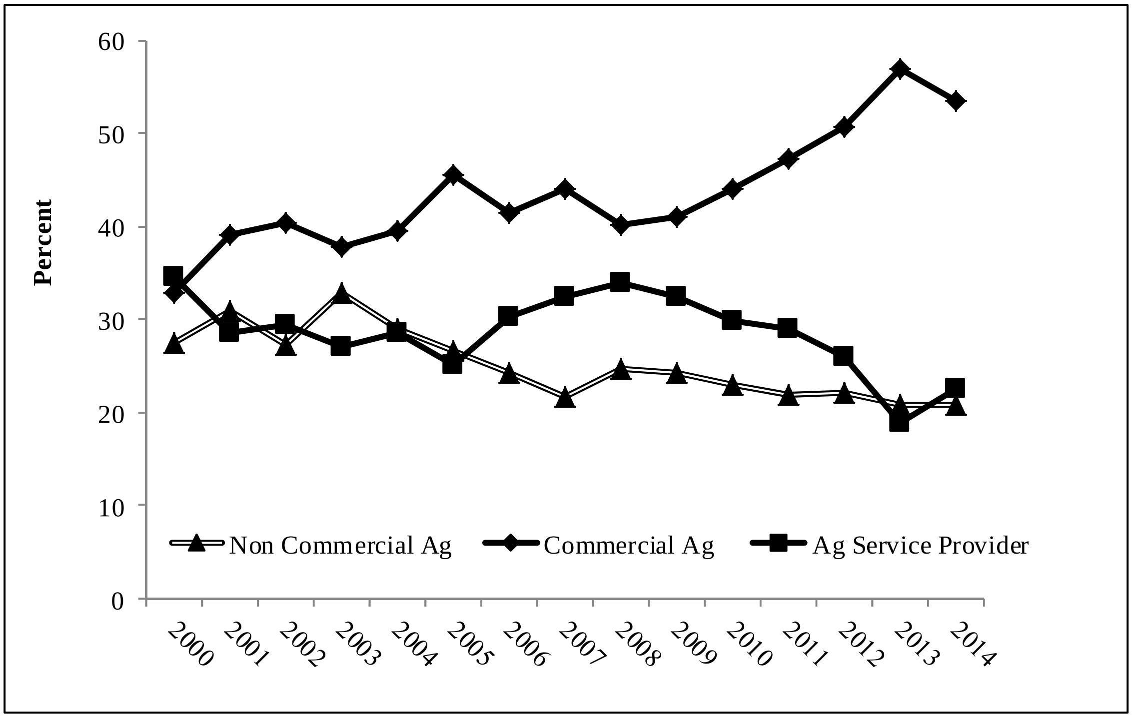


Table 3.3 defines the different variables considered and Table 3.4 reports the summary statistics for each of the variables. The variables are all using a three-year moving-average (previous two years and current year) as it is hypothesized that a typical producer would not make a purchase decision of a self-propelled forage harvester based on one year of results.[2] As an example, the milk price considered in 2000 is the average of the years 1998-2000. Table A.1 in the Appendix contains the correlation values for the variables.

[2] Models were estimated with contemporaneous prices, but as hypothesized, three-year averages typically resulted in a better fit. Thus, three-year averages were used for all variables for consistency.

Table 3.3: Variable Definitions.

Variable	Definition (Source)
SPFH Sold	Number of self-propelled forage harvesters sold (Ag Equipment Manufacturers)
AHP	Average Horsepower of self-propelled forage harvesters sold (calculated)
THP	Total horespower of self-propelled forage harvesters sold (calculated)
MPROD	Total annual milk produced in United States, three-year average (NASS)
DOPS5	Number of dairy operations with 500 head or more, three-year average (NASS)
DOPS	Number of dairy operations in the United States, three-year-average (NASS)
MCOWS	Total number of cows milked in the United States, three-year average (NASS)
ADSIZE	Average dairy size, number of cows, three-year average (NASS)
TYPCOW	Size of dairy for a typical cow, three-year average (calculated)
TYPCWT	Size of dairy for a typical hundred-weight of milk, three-year average (calculated)
TYPFED	Size of feedlot for a typical animal on feed, three-year average calculated)
TYPFAT	Size of feedlot for a typical animal sold, three-year average (calculated)
MPRICE	Average milk price received, three-year average (NASS)
CORNSILAG	Number of acres of corn harvested for silage, three-year average (NASS)
CORNPRICE	Annual price of corn received, three-year average (NASS)
NCA	Percent of purchasers generating less than $250,000 of gross farm revenue, three-year average (John Deere)
CA	Percent of purchasers generating more than $250,000 of gross farm revenue, three-year average (John Deere)
ASP	Percent of purchasers classified as ag service providers, three-year average (John Deere)

Table 3.4: Variable Summary Statistics.[1]

Variable	Unit	Mean	Minimum	Maximum	Std Dev
SPFH Sold	units	462	377	652	88.15
AHP	horsepower	598	520	675	59.06
THP	horsepower	279,758	195,927	439,774	75,637
MPROD	million pounds	181,401	162,415	202,720	13,341
DOPS5	# of operations	3,097	2,528	3,367	279.14
DOPS	# of operations	77,682	55,741	111,022	17,470
MCOWS	million head	9,152	9,032	9,245	65.49
ADSIZE	# of head	123	83	166	26.69
TYPCOW	# of head	1,119	534	1,650	381.10
TYPCWT	# of head	1,210	602	1,763	391.44
TYPFED	# of head	51,151	48,963	53,015	1,667
TYPFAT	# of head	22,827	21,075	25,472	1,188
MPRICE	$/cwt	15.84	13.12	21.20	2.40
CORNSILAG	acres	6,231	5,702	6,844	333.95
CORNPRICE	$/bu	3.38	1.88	6.28	1.52
NCA	% of purchasers	25.71	21.25	30.34	3.25
CA	% of purchasers	42.46	35.66	53.69	5.14
ASP	% of purchasers	29.19	22.44	32.83	2.99

[1]Number of observations = 15 for each variable

3.2 Models Specified

Three variables were chosen as the dependent variables for regression analysis: *SPFH Sold* (number of self-propelled forage harvesters sold per year), *THP* (total horsepower sold per year) and *AHP* (Average Horsepower sold per year). The objective was to predict the demand for horsepower of self-propelled forage harvesters in the future. After analyzing all the variables, six ordinary least squares (OLS) regression analysis were performed. The first analysis is intended to determine if there is a growth in *SPFH Sold*, *THP* and *AHP* over time.

These models are expressed as:

(1) *SPFH Sold* = *f* (*Year*),

(2) *THP* = *f* (*Year*),

(3) *AHP* = *f* (*Year*).

A second set of models were developed using the same three dependent variables of *SPFH Sold*, *THP*, and *AHP* along with various independent variables chosen from those listed in Table 3.4. Because there are reasons any of these independent variables might be appropriate, as previously discussed, the ones to include in the models is an empirical issue. Thus, the final variables used and reported here were those that resulted in the best fit of the data. The total amount of milk produced in terms of millions of pounds averaged over three years (*MPROD*) was selected as it represents the output of the dairy production and is highly correlated with average dairy size (*ADSIZE*), typical cow (*TYPCOW*), and typical hundredweight of milk (*TYPCWT*). The size of dairy operation for a typical cow averaged over three years (*TYPCOW*) is was chosen as it represents the size of the dairy operations and also has a near perfect correlation with the typical hundredweight of milk (*TYPCWT*). Two other independent variables are related to the purchaser of the self-propelled forage harvesters, the commercial ag (*CA*) and the Ag Service Provider (*ASP*) percent of self-propelled forage harvester purchasers. The final variables chosen are related the three-year average of the annual prices of corn (*CORNPRICE*) and milk (*MPRICE*). The importance of corn in the general agricultural economy cannot be overstated, especially given the impact of the corn prices on producer profitability in the recent past and expected impact in the near future. The price of milk is important as it is ultimately what many of the producers rely on for their revenue. These models are expressed as:

(4) *SPFH Sold* = *f* (*MPROD*, *CA*, *MPRICE*),

(5) *THP* = *f* (*TYPCOW*, *CA*, *MPRICE*),

(6) *AHP* = *f* (*TYPCOW*, *ASP*, *CORNPRICE*).

Models with the variables discussed in the section 3.1 were examined as well as models with different time periods other than a three-year average. It was discovered that the independent variables chosen ultimately explained the variations in the dependent variables the best, as discussed in the next section.

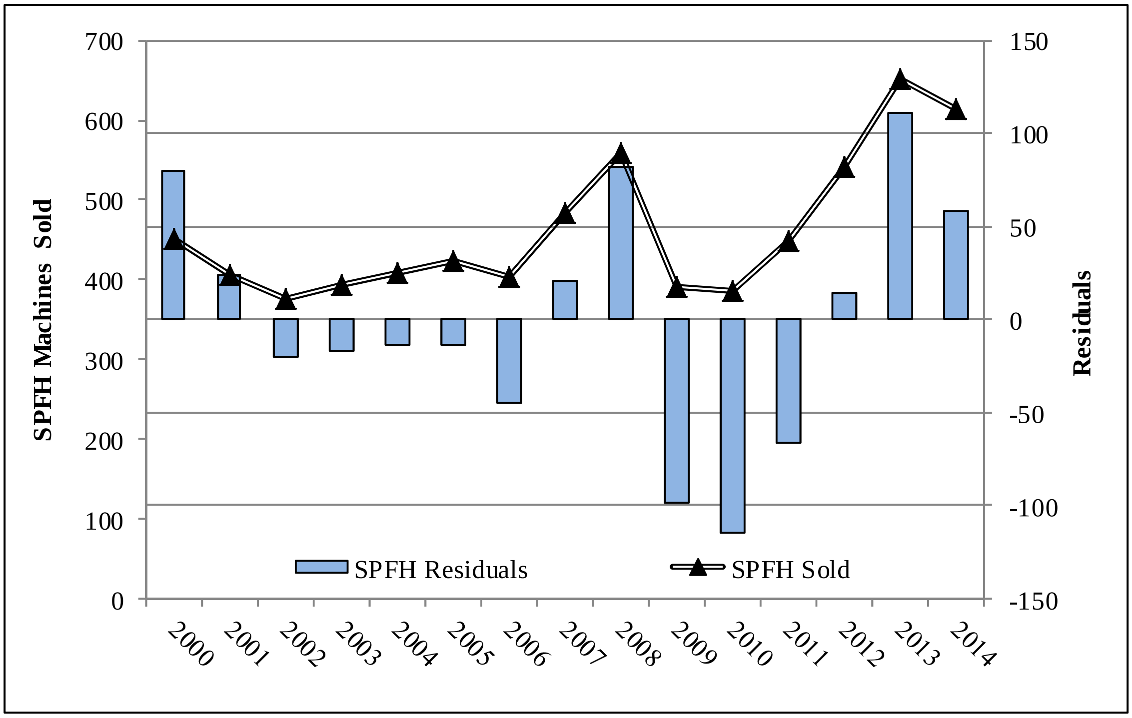
CHAPTER IV: RESULTS AND DISCUSSION

Equation (1), *SPFH Sold* = *f* (*Year*), is able to explain 44.5% of the variability in the Self-Propelled Forage Harvester sales (Table 4.1). The coefficient of the *Year* variable is 13.15, meaning that sales grow by 13.15 units each year. The t-statistic is 3.23, which is statistically significant at the 1% level. However, with an R^2 of 44.5%, this model explains less than half of the variability of SPFH sales. Figure 4.1 shows the actual Self-Propelled Forage Harvesters sold as compared to the residuals from the expected units sold.

Table 4.1: Regression Results, Self-Propelled Forage Harvester Sales, Equation 1, 2000-2014.

Variable	Estimated Coefficient	Standard Error	t Statistic	P-value
Intercept	-25,929.58	8,173.06	-3.17	0.007
Year	13.15	4.07	3.23	0.007
R-squared	0.445			

Figure 4.1: Actual Self-Propelled Forage Harvesters Sales and Residuals from Predicted, Equation 1, 2000-2014

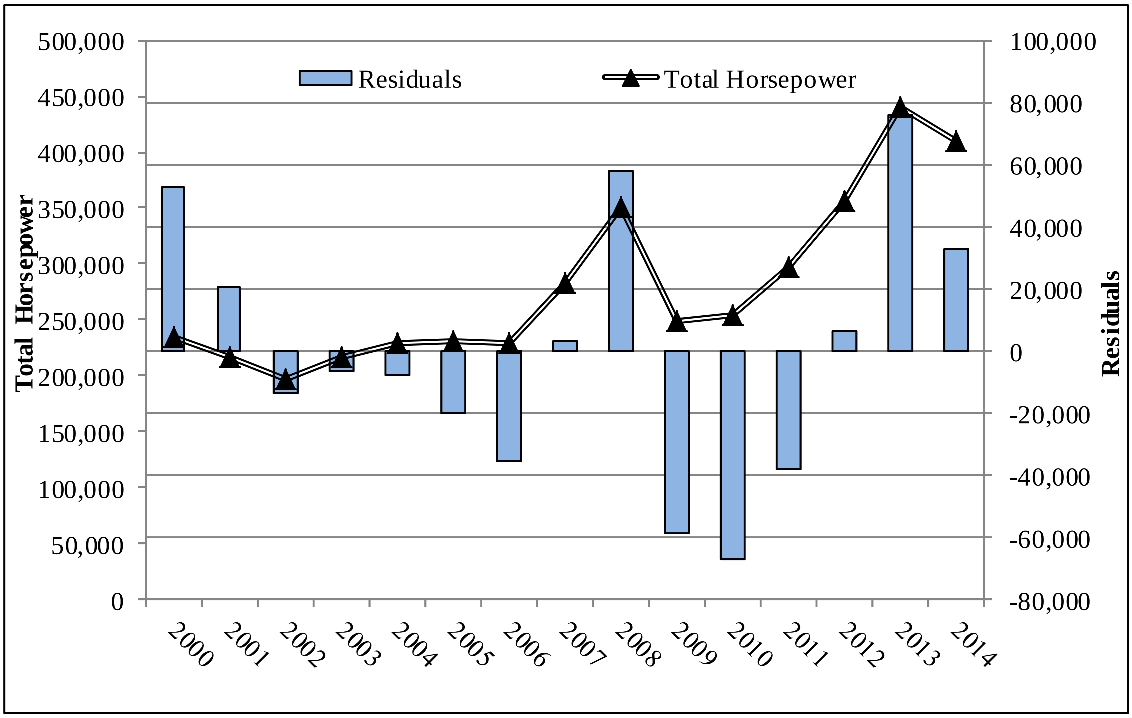


Equation (2), *THP* = *f* (*Year*), is able to explain 69.1% of the variability in the Total Horsepower sold each year (Table 4.2). The coefficient of the *Year* variable is 14,055.68; meaning the total horsepower purchased is expected to grow by 14,056 horsepower each year. The t-statistic is 5.39, which is statistically significant at the 1% level. However, with an R^2 of 69%, the explanatory power of the model likely could be improved. Figure 4.2 shows the actual total horsepower sold as compared to the residuals from the expected horsepower sold.

Table 4.2: Regression Results, Total Horsepower, Equation 2, 2000-2014.

Variable	Estimated Coefficient	Standard Error	t Statistic	P-value
Intercept	-27,929,982	5,236,244.97	-5.33	0.000
Year	14,055.68	2,608.98	5.39	0.000
R-squared	0.691			

Figure 4.2: Actual Total Horsepower and Residuals from Predicted, Equation 2, 2000-2014

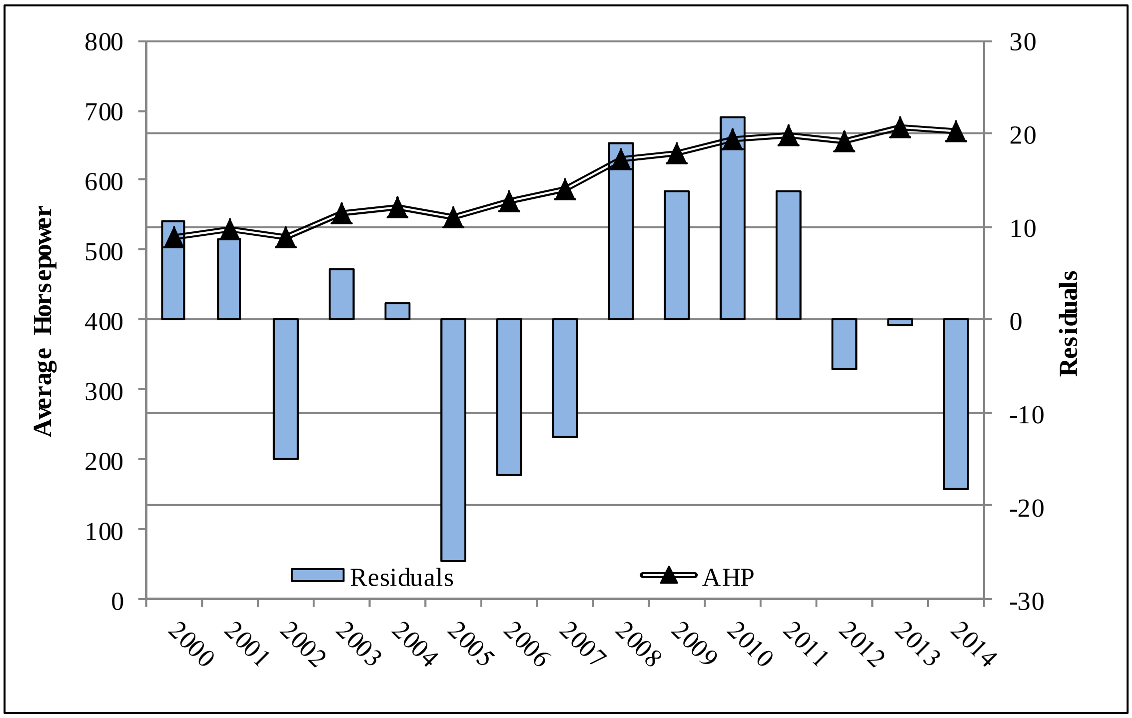


The third equation, *AHP* = *f* (*YEAR*), was able to explain 93.6% of the variability in average horsepower (Table 4.3). The coefficient of 12.78 means that the average horsepower is expected to grow at a rate of 12.78 horsepower per year. The t-stat for this coefficient is 13.80, which is significant at the 1% significance level. Figure 4.3 shows the actual average horsepower sold as compared to the residuals from the model.

Table 4.3: Regression Results, Average Horsepower, Equation 3, 2000-2014

Variable	Estimated Coefficient	Standard Error	t Statistic	P-value
Intercept	-25,043.81	1,858.65	-13.47	0.000
Year	12.78	0.93	13.80	0.000
R-squared	0.936			

Figure 4.3: Actual Average Horsepower and Residuals from the Predicted, Equation 3, 2000-2014

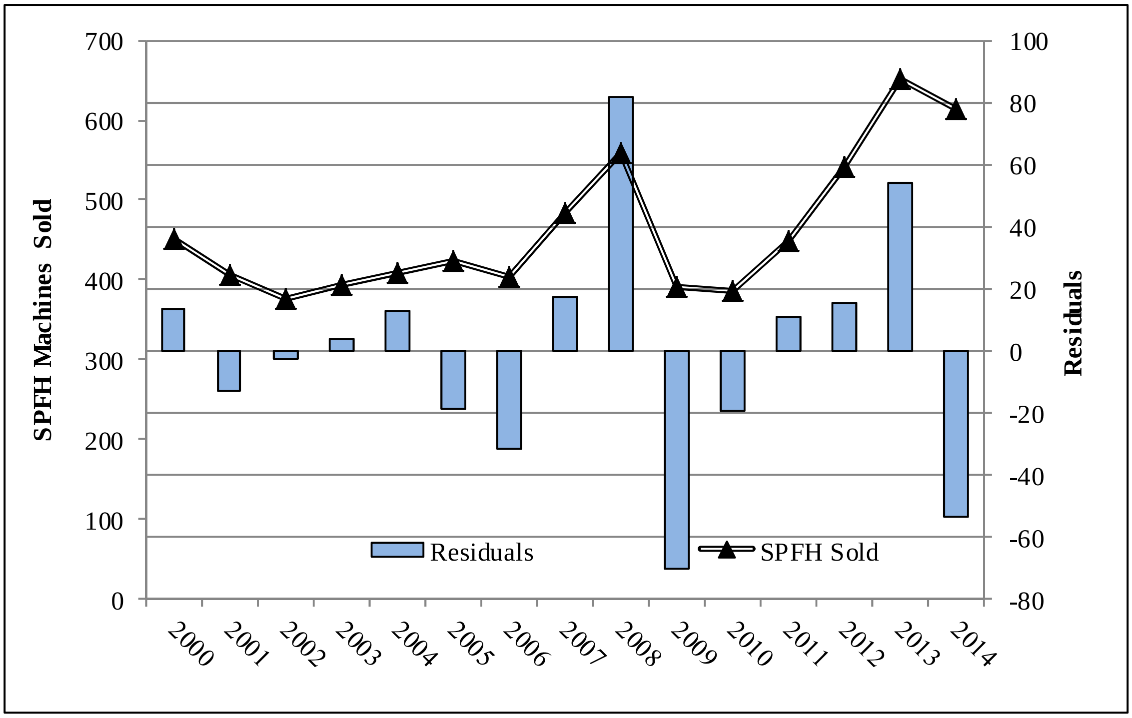


Equation 4, which brings in milk production, percent purchases by commercial ag customers, and milk price; was able to explain 81.2% of the variability in self-propelled forage harvesters sold from 2000 to 2014 (Table 4.4). The coefficient for the milk production (*MPROD*) variable is -0.01, which means as the three-year average for milk production increases by 1 million pounds; the sales of self-propelled forage harvester will decrease by 0.01 units. The t-stat for this coefficient is -2.25, which is significant at the 5% significance level. The coefficient for the *CA* variable is 7.26; meaning for every one percentage point increase in the three-year average percent of purchases coming from the commercial ag customer segment, total sales will increase by 7.26 units. The t-stat for this coefficient is 1.06, which is not significant. The coefficient for the *MPRICE* variable is 44.38, which means for every $1 increase in the three-year average price per hundredweight of milk, the sales of a self-propelled forage harvester will increase by 44.38 units. The t-stat for this coefficient is 2.72, which is significant at the 5% significance level. Figure 4.4 shows the relationship between the predicted average self-propelled sales and the expected sales.

Table 4.4: Regression Results, Self-Propelled Forage Harvesters Sold, Equation 4, 2000-2014.

Variable	Estimated Coefficient	Standard Error	t Statistic	P-value
Intercept	428.97	241.50	1.78	0.103
MPROD	-0.01	0.00	-2.25	0.046
CA	7.26	6.87	1.06	0.314
MPRICE	44.38	16.31	2.72	0.020
R-squared	0.812			

Figure 4.4: Actual Self-Propelled Forage Harvesters Sales and Residuals from Predicted, Equation 4, 2000-2014

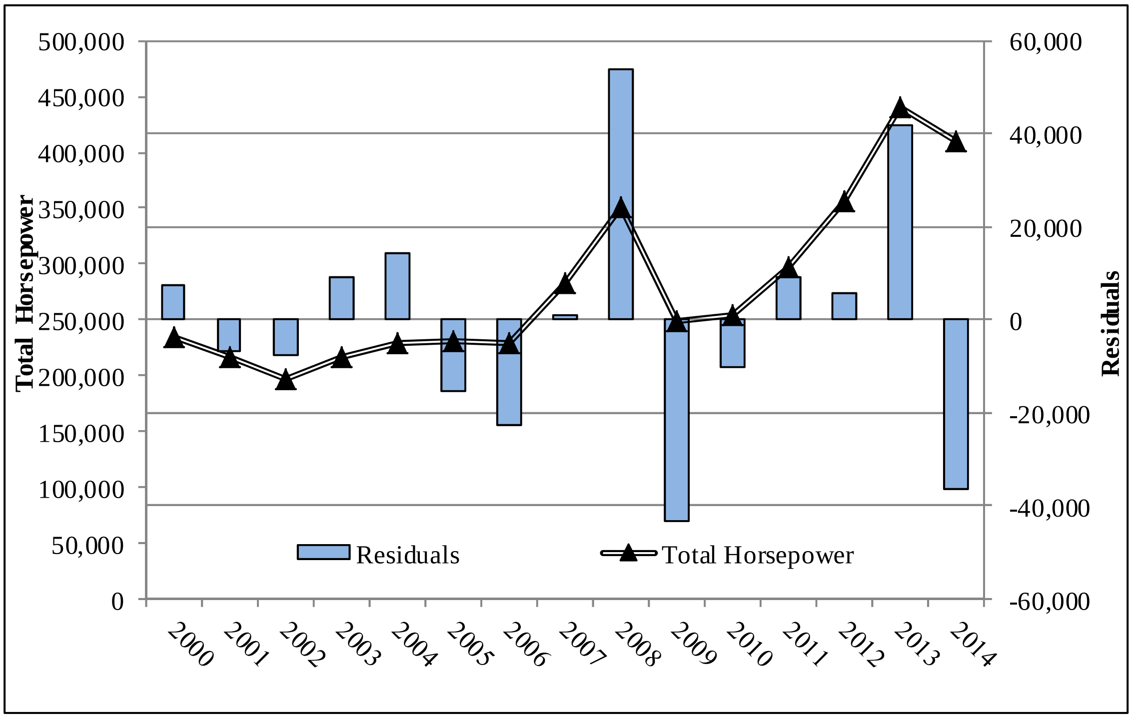


Equation 5, *THP* = *f* (*TYPCOW*, *CA*, *MPRICE*), was able to explain 88.4% of the variability in total horsepower sold from 2000 to 2014 (Table 4.5). The coefficient for the *TYPCOW* variable is -35.16, which means as the three-year average for dairy operation size for a typical cow increases by 1 cow; the total horsepower of self-propelled forage harvesters sold in a year will decrease by 35.16 horsepower. The t-stat for this coefficient is -0.77, which is not significant. The coefficient for the *CA* variable is 3,950.34; meaning for every 1% increase in the three-year average of the commercial ag customer segment purchasing a self-propelled forage harvester, the total horsepower sold will increase by 3,950 horsepower. The t-stat for this coefficient is 0.86, which is not significant. The coefficient for the milk price variable is 26,444.49, which means for every $1 increase in the three-year average of the price of milk, the total horsepower of self-propelled forage harvesters sold will increase by 26,444 horsepower. The t-stat for this coefficient is 2.58, which is significant at the 5% significance level. Figure 4.5 shows the relationship between the predicted total horsepower of self-propelled forage harvesters sold and the expected total horsepower sold.

Table 4.5: Regression Results, Total Horsepower, Equation 5, 2000-2014.

Variable	Estimated Coefficient	Standard Error	t Statistic	P-value
Intercept	-267,585.43	94,741.84	-2.82	0.017
TYPCOW	-35.16	45.64	-0.77	0.457
CA	3,950.34	4,600.65	0.86	0.409
MPRICE	26,444.49	10,239.31	2.58	0.025
R-squared	0.884			

Figure 4.5: Actual Total Horsepower and the Residuals from Predicted, Equation 5, 2000-2014

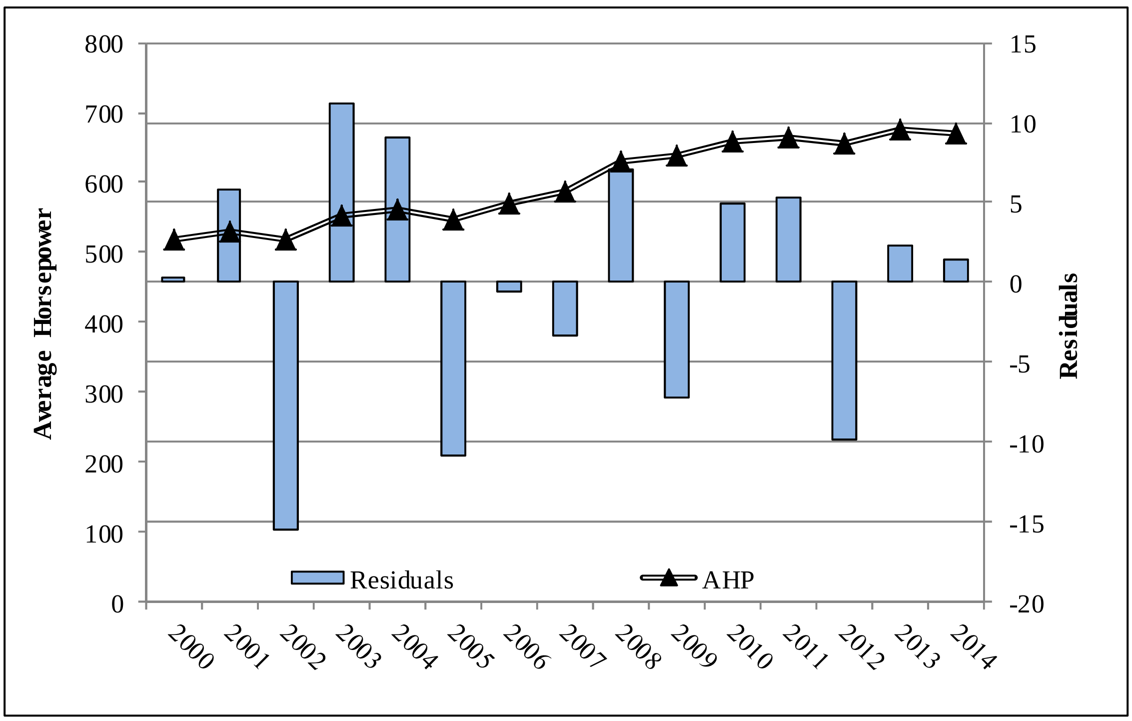


Equation 6, which models average horsepower (*AHP*) as a function of size of dairy for typical cow (*TYPCOW*), percent of purchases from Ag Service Providers (*ASP*), and corn price (*CORNPRICE*), was able to explain 98.2% of the variability in average horsepower from 2000 to 2014 (Table 4.6). The coefficient for the *TYPCOW* variable is 0.13, which means as the three-year average for dairy operation size for a typical cow increases by 1 cow; the average horsepower for a self-propelled forage harvester sold will increase by 0.13 horsepower. The t-stat for this coefficient is 7.44, which is significant at the 1% significance level. The coefficient for the Ag Service Provider is 2.566; meaning for every 1% increase in the three-year average of Ag Service Provider customer segment purchasing a self-propelled forage harvester, the average horsepower will increase by 2.57 horsepower. The t-stat for this coefficient is 2.86, which is significant at the 5% significance level. The coefficient for the corn price variable is 8.50, which means for every $1 per bushel increase in the three-year average price of corn, the average horsepower of a self-propelled forage harvester will increase by 8.50 horsepower. This positive sign is what was hypothesized, i.e., as the value of corn (hence corn silage) increases, larger harvesters will be purchased. However, this also suggests that as corn prices decrease, the average horsepower would decline. This likely would not be the case as technology seldom "backs up." While there was a positive (marginally significant) relationship between average horsepower and corn price for the 15-year time period analyzed it may not be the case moving forward. It is possible that as corn prices decrease the total machines sold could be affected, but the average horsepower likely would not decrease. The t-stat for this coefficient is 1.90, which is significant at the 10% significance level. Figure 4.6 shows the relationship between the predicted average horsepower level and the actual average horsepower level.

Table 4.6: Regression Results, Average Horsepower, Equation 6, 2000-2014.

Variable	Estimated Coefficient	Standard Error	t Statistic	P-value
Intercept	350.99	29.45	11.92	0.000
TYPCOW	0.13	0.02	7.44	0.000
ASP	2.57	0.90	2.86	0.016
CORNPRICE	8.50	4.47	1.90	0.084
R-squared	0.982			

Figure 4.6: Actual Average Horsepower and the Residuals from the Predicted, Equation 6, 2000-2014



CHAPTER V: CONCLUSION

The results of this analysis found the model that did the best job of explaining the variability of the primary dependent variable of focus (average horsepower) was equation (6), the Average Horsepower of the self-propelled forage harvesters sold (*AHP)* as a function of the typical cow (*TYPCOW*), percent of purchases from Ag Service Provider customer segment (*ASP*), and the price of corn (*CORNPRICE*) variables. Not only were the coefficients of these variables significant at the 1%, 1%, and 10% levels, the entire model was able to explain 98.2% of the variability. The results with regard to the *TYPCOW* and *ASP* are consistent with the results shown in Figure 1.1 with regard to the price/horsepower decreasing as the machines get larger. As dairies or agricultural service providers continue to grow, their opportunity to use more horsepower continues to grow as well. Therefore, the cost of operating the harvesters decreases as they get larger with full utilization of the horsepower. Models were also estimated to explain the variability in self-propelled forage harvesters sold and total horsepower sold. Due to the limitations of the data used for this analysis, having only 15 observations for each of the variables, future research is needed to continue to analyze the horsepower growth.

Another important factor to consider is that the size of the self-propelled forage harvester market is not very large and there are relatively few customers purchasing these machines. A recommendation for further research is to survey the actual purchasers of the equipment to further understand their requirements.

Horsepower was used as a proxy for productivity, but productivity does not have to come from simply a bigger engine. Other methods of improving capacity of self-propelled forage harvesters, such as crop flow through the machine and electric drives to operate functional areas that have large horsepower requirements could change how rated engine horsepower is valued in the marketplace.

Another area of analysis is the impact of previously owned self-propelled forage harvesters on the overall market. With relatively few customers, and those customers continue to be less, there needs to be a market developed for the high horsepower, and very expensive used self-propelled forage harvesters. The availability and price of used equipment could have as big of an impact on this market as any of the other variables.

One final area of research that could be added is the impact of price on the sale of the machines. The relationship between price and horsepower typically is not linear on large equipment. As the machines continue to increase in horsepower, the price required to purchase, maintain, and repair the machines increase exponentially.

This thesis is a place to begin for analyzing the self-propelled forage harvester market, but as discussed, there many more factors that can be researched and added to improve this model.

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APPENDIX

Table A.1: Correlation Between Variables

	Year	SPFH Sold	AHP	THP	MPROD	DOPS5	DOPS	MCOWS	ADSIZE	TYPCOW	TYPCWT	TYPFED	TYPFAT	MPRICE	CORNSILAG	CORNPRICE	NCA	CA	ASP
Year	**1.0000**	0.6672	0.9675	0.8311	0.9946	0.9431	-0.9815	0.4483	0.9993	0.9946	0.9957	-0.3284	0.6922	0.9079	0.0406	0.9378	-0.9155	0.9179	-0.4753
SPFH Sold	0.6672	**1.0000**	0.6134	0.9646	0.6876	0.4791	-0.5816	0.2905	0.6635	0.6226	0.6298	0.1421	0.7641	0.8501	0.4146	0.7519	-0.7047	0.8174	-0.6038
AHP	0.9675	0.6134	**1.0000**	0.7978	0.9750	0.9343	-0.9476	0.5836	0.9735	0.9832	0.9814	-0.3778	0.6169	0.8606	-0.0970	0.9331	-0.9197	0.8199	-0.2925
THP	0.8311	0.9646	0.7978	**1.0000**	0.8486	0.6728	-0.7575	0.4194	0.8302	0.8009	0.8058	0.0068	0.7959	0.9343	0.3037	0.8880	-0.8371	0.9017	-0.5733
MPROD	0.9946	0.6876	0.9750	0.8486	**1.0000**	0.9279	-0.9650	0.5198	0.9964	0.9930	0.9937	-0.3174	0.7143	0.9263	0.0198	0.9520	-0.9454	0.9084	-0.4274
DOPS5	0.9431	0.4791	0.9343	0.6728	0.9279	**1.0000**	-0.9848	0.3543	0.9429	0.9591	0.9595	-0.5638	0.5880	0.7527	-0.1067	0.8079	-0.8455	0.7746	-0.2888
DOPS	-0.9815	-0.5816	-0.9476	-0.7575	-0.9650	-0.9848	**1.0000**	-0.3482	-0.9791	-0.9823	-0.9838	0.4521	-0.6550	-0.8342	-0.0022	-0.8673	0.8721	-0.8681	0.4293
MCOWS	0.4483	0.2905	0.5836	0.4194	0.5198	0.3543	-0.3482	**1.0000**	0.4787	0.4967	0.4889	0.0454	0.3579	0.5157	-0.1816	0.6098	-0.5680	0.3096	0.1689
ADSIZE	0.9993	0.6635	0.9735	0.8302	0.9964	0.9429	-0.9791	0.4787	**1.0000**	0.9967	0.9974	-0.3280	0.6937	0.9105	0.0316	0.9422	-0.9200	0.9111	-0.4567
TYPCOW	0.9946	0.6226	0.9832	0.8009	0.9930	0.9591	-0.9823	0.4967	0.9967	**1.0000**	0.9999	-0.3852	0.6588	0.8857	-0.0342	0.9318	-0.9216	0.8757	-0.3890
TYPCWT	0.9957	0.6298	0.9814	0.8058	0.9937	0.9595	-0.9838	0.4889	0.9974	0.9999	**1.0000**	-0.3823	0.6677	0.8891	-0.0229	0.9312	-0.9223	0.8818	-0.3992
TYPFED	-0.3284	0.1421	-0.3778	0.0068	-0.3174	-0.5638	0.4521	0.0454	-0.3280	-0.3852	-0.3823	**1.0000**	0.0095	-0.1009	0.6653	-0.0855	0.3934	-0.0421	-0.4007
TYPFAT	0.6922	0.7641	0.6169	0.7959	0.7143	0.5880	-0.6550	0.3579	0.6937	0.6588	0.6677	0.0095	**1.0000**	0.8214	0.4851	0.6713	-0.7142	0.8143	-0.5596
MPRICE	0.9079	0.8501	0.8606	0.9343	0.9263	0.7527	-0.8342	0.5157	0.9105	0.8857	0.8891	-0.1009	0.8214	**1.0000**	0.2027	0.9261	-0.9072	0.9398	-0.5529
CORNSILAG	0.0406	0.4146	-0.0970	0.3037	0.0198	-0.1067	-0.0022	-0.1816	0.0316	-0.0342	-0.0229	0.6653	0.4851	0.2027	**1.0000**	0.0962	0.1135	0.3549	-0.7344
CORNPRICE	0.9378	0.7519	0.9331	0.8880	0.9520	0.8079	-0.8673	0.6098	0.9422	0.9318	0.9312	-0.0855	0.6713	0.9261	0.0962	**1.0000**	-0.8919	0.8886	-0.4541
NCA	-0.9155	-0.7047	-0.9197	-0.8371	-0.9454	-0.8455	0.8721	-0.5680	-0.9200	-0.9216	-0.9223	0.3934	-0.7142	-0.9072	0.1135	-0.8919	**1.0000**	-0.8238	0.2491
CA	0.9179	0.8174	0.8199	0.9017	0.9084	0.7746	-0.8681	0.3096	0.9111	0.8757	0.8818	-0.0421	0.8143	0.9398	0.3549	0.8886	-0.8238	**1.0000**	-0.7479
ASP	-0.4753	-0.6038	-0.2925	-0.5733	-0.4274	-0.2888	0.4293	0.1689	-0.4567	-0.3890	-0.3992	-0.4007	-0.5596	-0.5529	-0.7344	-0.4541	0.2491	-0.7479	**1.0000**