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Mechanization Potential for Expanding Midwestern Fruit and Vegetable Enterprises

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Mechanization potential for expanding midwestern fruit and vegetable enterprises

by

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DEDICATION

I would like to dedicate this thesis to my parents, Mikkel and Barbara Pates without whose support I would not have been able to complete this work. I would also like to thank my friends and family for their loving guidance and financial support during the writing of this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Midwestern fruit and vegetable farmers face challenges in expanding their farms. Growing fruit and vegetables remains a labor intensive industry and most of the country's commercial production takes place on large scale farms in the Western United States. Mechanization may aid farmers in scaling up production by offsetting labor costs. This report uses a six-farm case study and a survey to examine the trends of both labor and machine use over different levels of production. Larger farms tended to use more labor and machinery but machinery seems to exhibit a degree of labor savings potential. The context of expansions impact the labor tradeoff potential of machinery. Some crops are more difficult to mechanize and expansions into dissimilar crops tended to reduce the machinery-labor tradeoff potential. A dynamic optimization model was constructed to simulate farm expansions to address issues of timeliness and crop mix context.

CHAPTER 1. OVERVIEW

1.1 Background

Western states, notably the state of California, contribute the majority of the nation's fruit and vegetable (FV) acres and sales. In 2007, the top three producers of non-citrus fruit and vegetables, California, Washington, and Idaho, accounted for over 51% of the nation's harvested acres. California has over a third of national acres. The West accounts for around 60% of the national vegetable sales, 50% of national vegetable acreage, and nearly 80% of national non-citrus fruit acreage (USDA (2007, 2012)). These states have natural advantages in growing FV crops including a close proximity to migrant workers, longer growing seasons, and a greater access to major metropolitan areas (as in California). However, according to the latest U.S. Census of Agriculture, direct sales from growers to consumers rose by 105% from 1997 to 2007. Although direct sales account for less than one percent of total agricultural sales, it is one of the fastest growing sectors of agriculture and exceeded the 2007 overall agricultural sales growth by 57%. FV farms are an important component of the direct sales market and account for 56% of total direct sales (Martinez (2010)). This recent trend suggests that areas that do not traditionally produce these goods have new market opportunities and challenges to profitably meet the demand of local food consumers.

Midwestern FV farms differ even within the region. The midwestern states with the most vegetable acreage over the last 20 years were Wisconsin, Minnesota, and Michigan respectively: Iowa, Kansas, and South Dakota rounded out the bottom. Data on the number of farms by vegetable acreage show differences between the farm size distributions of larger producing versus smaller producing states within the Midwest. This means that the differences in production are not due entirely to simply more farms but differences in the average the sizes of farms between the states. Higher producing states tended to have a multi-modal farm size distribution peaking both around one to five vegetable acres and around 50 vegetable acres. This may indicate that there are two scales that are optimal for farmers. Nebraska was the smallest producing state that the census reported relative vegetable farm size in 2007. In previous years, Nebraska's size distribution closely resembled Iowa's. Lower producing states tended to have a distribution that resembled a truncated normal distribution that peaks at acreages of one to five acres (Figure 1.1). This could indicate that states with lower levels of vegetable production are not achieving the economies of scale that the larger states are. This same analysis also shows that there are inter-regional differences between farms in California. Relative to the Midwest, California's mid-range vegetable farms are slightly larger and the state has a far higher proportion of farms that are producing on over 250 vegetable acres (Figure 1.2). These charts suggest that there may be room for farms within the Midwest to economically increase production to accommodate the rising local demand.

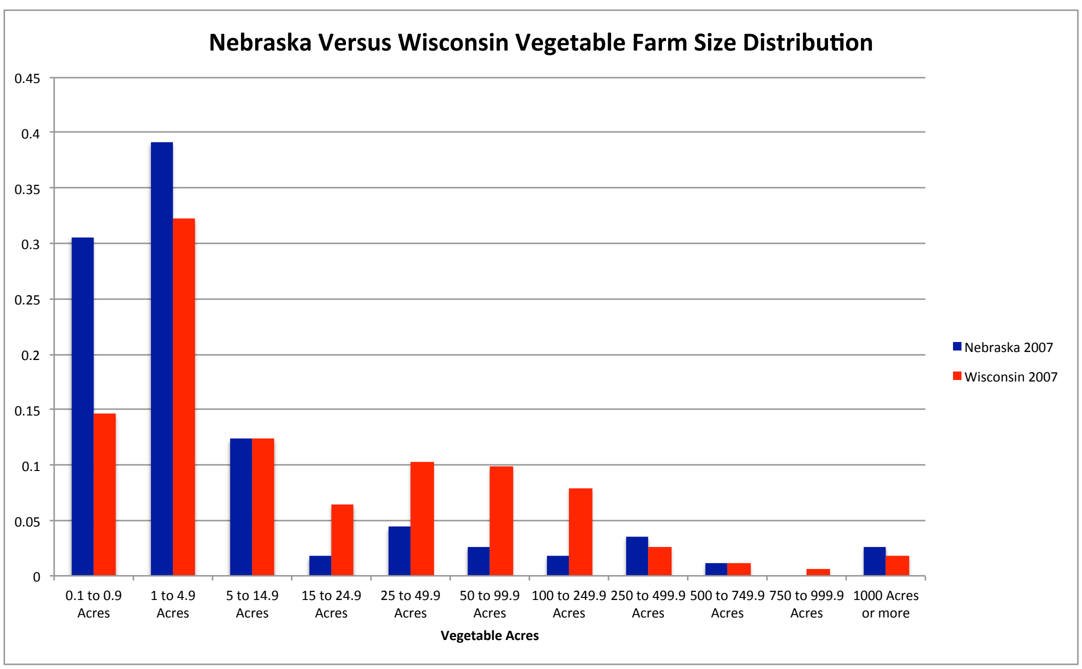

Figure 1.1: Nebraska Versus Wisconsin Vegetable Farm Size Distribution

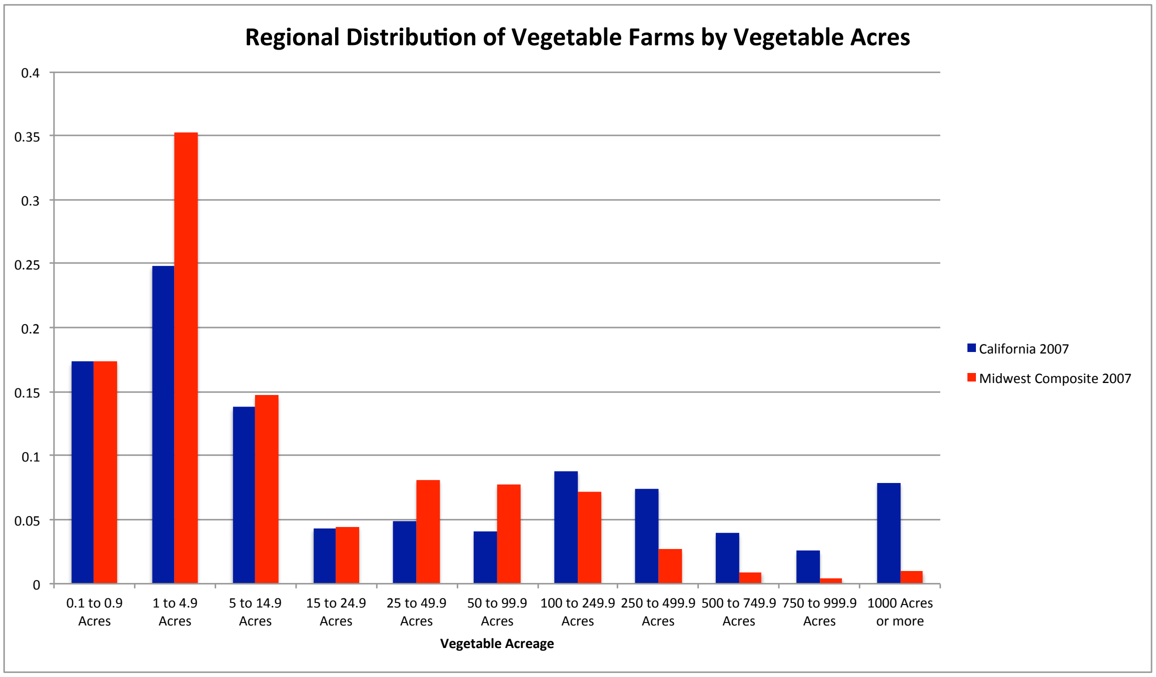

Figure 1.2: California Versus Midwestern Vegetable Farm Size Distibution

Labor is an important input to the FV industry and currently makes up 42% of total US FV variable costs (Calvin and Martin (2010)). Using machinery to help complete farm tasks is one method to increase energy efficiency on a farm and is a driving factor for the reduction in farm work hours since the 1900s (Landers (2000), pp. 1-2). It follows that using machinery may enable local FV farms to expand working acreage with the same labor force or to reduce the amount of laborers on the farm while sustaining its acreage. Along with emerging market opportunities, the Midwest has significant farm labor challenges. Many counties are suffering from rural flight and the region's median farmworker wages exceed the national average by 18% (BLS (2011)). These challenges make the determination of the labor-capital tradeoff potential of farm machinery in a traditionally labor-intensive enterprise of significant interest to growers seeking to start or expand a FV enterprise.

Mechanizing for these farms can be challenging. The development and commercial implementation of FV machines has been sluggish relative to conventional field grain crops and FV specific machines may be expensive and crop specific. Many FV crops are still without viable mechanized systems. Mechanization of fresh FV crops are particularly challenging since damage from mechanized treatment is visible to the final consumer and could reduce the marketability (Sarig et al. (2000)). These challenges make it difficult to find machines that are capable of aiding FV production.

The study will examine data from an industry survey and a multi-case study. The survey, conducted at several midwestern fruit and vegetable grower conferences in early 2012, yielded information on 44 growers in Iowa, Wisconsin, and Minnesota. Among other things, the survey asked for the acreage of the farm, specialty fruit and vegetable crops grown, a seasonal profile of labor, and information on the machine fleet with a ranking of the top five most important machines within the enterprise. The multi-case study collected labor tradeoff information on six expanding FV enterprises within the state of Iowa over the fall and winter of 2012 and 2013 respectively. Interviewees were questioned on context sensitive aspects of their expansion and machinery adoption choices such as the "ease" of finding labor, relevant machinery and their marketing methods.

The farm's size, crop mix, and labor force all impacted the mechanization of FV farms. As expected, surveyed farms that used more machinery tended to employ less labor. Several farms in the case study specifically purchased machinery in order to reduce labor costs. The way the farm marketed did not seem to impact mechanization but the scale and composition of production had major impacts. As expected, larger farms tended to use more machinery and employ more labor. However, as farms produced a more diverse set of crops, they tended to trade labor for machinery more distinctly. This seems to be because machines offered have greater usability when the farm grew more similar crops. Several case study farms purchased machinery because of its ability to perform tasks for multiple crops on the farm and offer the most cost savings. For many farms, scale and the availability of economical alternatives to hand labor kept them from mechanizing certain tasks. The common tasks that were mechanized were were tilling, seeding, and the management of soil and weeds, while for many crops, harvesting was performed by hand with the exception of root crops.

1.2 Farm Mechanization Literature

Because the topic of this project is centered on production, the literature review was targeted on the inputs of FV farms. There is little contemporary academic research in the field of economics primarily that focuses on the production and inputs of the FV industry. The horticulture community has presented research specific FV technology but this largely focuses on specific technology and specific crops. While this is useful in their field it is difficult to make broader generalizations of the impact that technology would have on the farm as a whole since machinery could be used for a single crop or have other applications for the farm in addition to the researched tasks. This literature review will focus farm-level production technology as it relates to the broader FV farming community. To keep this review structured, research will be organized by general farm-level constraints for production systems laid out by Landers (2000): biological constraints, physical constraints, operational constraints, and environmental constraints (Landers (2000), pp.7-11). The review will conclude with some historical developments of machinery in the FV industry.

Biological constraints as the name suggests, relate to the biology of the plant. A crop's biology largely dictates the needs of the crop as it develops including task timing, optimal moisture, soil condition, and potentially the feasible labor and machinery combinations needed to raise the crop. Examples of these biological constraints include the required number of heat units a crop must absorb before it progresses through its stages of development and the prevalence of diseases and efficacy of chemical treatments in certain plants. These constraints are stated formally in various planting guides and crop specific articles and journals such as HortTechnology (Edwards (2009); MVPGCG (2013)). A common biological constraint that impacts mechanical harvesting potential is the uniformity of plant development. Mechanical harvesters often offer efficiency gains over hand labor by harvesting crops en masse. If the crop does not develop at the same rate, the use of mechanical harvesters will cause waste since both developed and undeveloped fruits and vegetables will be taken out of the field indiscriminately. For this reason, the development of many harvesting systems was coordinated with breeding research (Sarig et al. (2000)).

Physical constraints relate to the design of machinery used on the farm. Among other things, machinery horsepower, size and weight, serviceability, and speed impact the field efficiency. Size and speed likely increase machine efficiency but increased weight may damage the soil (Landers (2000); Hunt (2001)). Several researchers divided FV machine systems into three categories: labor aids, labor saving, and labor replacing systems. Labor aids are systems that reduce the effort required by laborers to perform a certain task. These aids could conceivably bolster the supply for labor in the FV industry as it improves working conditions and saves "back work". Labor saving systems perform the work originally done by workers. These systems are akin to combines in the row crop industry and increasing labor productivity on farms, often by performing tasks en masse. Robotic systems attempt to mimic the actions and senses of laborers. Advances in electronic optics and dexterity of mechanical effectors has enabled machines to do the work of sorting, packaging and, in some instances picking previously performed by workers. While robotic systems enable equal or greater productivity versus laborers, they can be quite costly and in some instances difficult to implement. Around 20% to 30% of the crop is unharvestable with robotic systems (Huffman (2012); Sarig et al. (2000)).

Operational constraints pertain to farm workers and the characteristics of a farm as a whole. These include the planning, management, and risk preferences of the primary farm manager and the ability of farm workers. In their research on agricultural mechanization J.C. Hadrich et al. (2012) used a "two hurdle" econometric approach to study the direction and degree of correlation that financial, structural, and tax policy variables have on machinery purchases. The model considered both how likely a grower would be to purchase equipment and the purchase intensity, quantified by the machinery purchase price divided by gross sales. Interestingly, this study included farm types as one of the variables of interest. Farms with 80% or more gross sales from grains/oilseeds, with 80% of gross sales from livestock, and with 80% of gross sales from a combination of grains/oilseeds and livestock, referred to as "combination farms", were considered. Combination farms were significantly less likely to purchase machinery than grain/oilseed farms but are likely to spend more relative to gross sales when purchases were made. This is of interest since many FV growers have more than one specialty crop or activity on their farms. One would expect relatively less interest in purchasing equipment as their enterprise is more fragmented and are less able to fully exploit the economies of scale of a given equipment purchase. The higher purchase intensity of combination farms seems to support this since specialized equipment may be more expensive in the Midwest due to constricted supplies. The model showed that more experienced principal operators were less likely to purchase machinery and had smaller purchase intensities. This likely reflects the impact of the lifetime of the enterprise since purchases of durable capital by farmers nearing retirement will not be able to provide services to the enterprise over enough time to justify heavy capital purchases of the machinery (Hadrich et al. (2012)).

Finally, environmental constraints are those that are not associated with the farm but the environment that the farm is in. These constraints include the weather and the farm's soil type. Taken together, environmental constraints as well as the previously discussed constraints segue into a prevalent concern in agriculture, timeliness. The success of field preparation, planting, and harvesting performance are greatly impacted by the time they are conducted. Landers (2000) puts it best, "The difference between a good farmer and a poor farmer can be as little as two weeks" (pp. 4). Performing farm activities in a timely manner optimizes the biological efficiency of the crop and reduces risks from environmental and managerial factors. Harvests performed too early or too late may result in excess moisture content or field loss and spoilage respectively (Hunt (2001), pp. 274-276; Landers (2000)). Planting too late may result in suboptimal sunlight exposure throughout the crop's stages of development resulting in yield losses (Edwards (2009)). As timing is important to planting, it is also important that field preparation must be performed in a timely manner. This is particularly important because beds must be available to accept seed at the time of planting. Suboptimal timing in preparation may force a farmer to resurface the soil. This may result in beds that are too fine which leads to inadequate nutrient and moisture content and may even damage the soil due to excess compaction (Landers (2000), pp. 73-74).

Farmers must choose inputs carefully to accommodate the needs of the crops and adhere to the farm, location, and temporal constraints of the farm as a whole. In his book, Landers (2000) focused on machinery selection from the owner/operator's prospective. The book, though frequently referencing machinery experiment data, stresses farm management practices especially collecting personal field data through journals. These journals help owners collect important data to produce tailored statistics such as labor and machinery profile charts. These charts are useful for establishing peaks and valleys of average labor and machine capacity demands and is especially useful in planning machinery acquisitions. A diligent farmer can collect data on how many work hours a given task needs and the optimal periods these tasks must be completed. With this information, the owner can plan how many machines or laborers are required throughout the year as shown in figure 1.3[1].

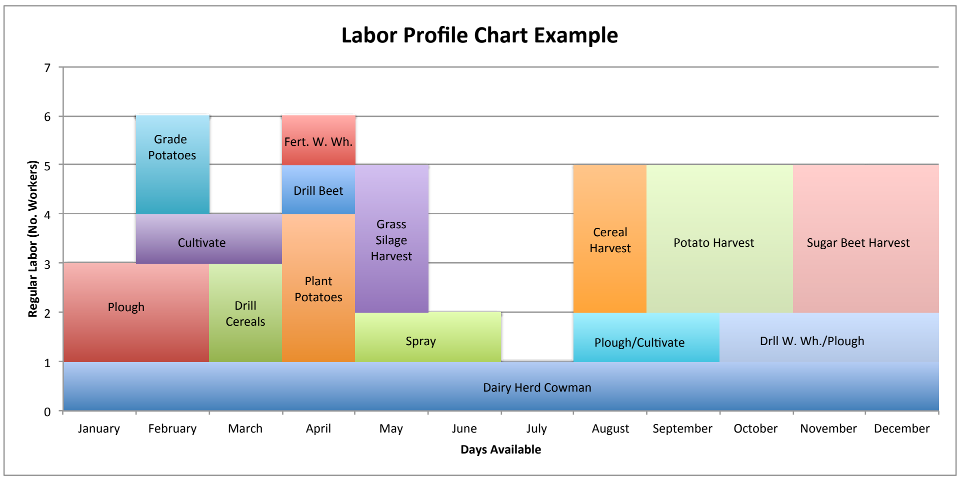

Figure 1.3: Labor Profile Chart Example

In a recent edition of Choices, an online food and farm magazine, Huffman (2012) provides an overview of current FV machinery development. With the exception of the potato digger, which dates back to the 1900s, most FV mechanization has lagged behind grain crop mechanization (Huffman (2012)). The task of harvesting is a point of interest in much of the literature on FV mechanization. Hand harvesting can account for over 50% of the labor requirements in a given enterprise and therefore mechanical harvesting can potentially offer the most benefit to growers wishing to mitigate labor usage. In their paper Sarig et al. (2000) presented a history for generic FV mechanization development, identifies crops that are not yet harvestable by machines, and offers reasons why mechanizing FV harvesting is difficult. Most harvesting technology development, with the exception of early developments for below ground

[1]This profile example was taken from page 13 of Farm Machinery: Selection and Management (Landers (2000)).

crops, occurred from 1960 to 1975. Innovation was largely pushed by the terminal years of the Bracero Program that ended in 1964. This was a joint agreement through the US and Mexican governments that allowed the US railroad and agricultural industries to legally employ Mexican workers between 1942 to 1964 to aid these industries which faced labor shortages. After the elimination of the program, many growers sought ways to deal with the loss of labor. Through the efforts of mechanization in this major improvements were made in FV harvesting (Huffman (2007, 2012); Sarig et al. (2000); Scruggs (1963)).

The tomato harvester is perhaps the most commonly acclaimed FV mechanical harvester. The tomato harvester helped California become a dominant global producer of tomatoes bound for processing and dramatically reduced required labor by 66%. Smaller versions of the California tomato harvester have been produced for Midwestern growers. Though these harvesters are a good way to increase efficiency and offset labor costs, because of the rough mechanical treatment, these harvesters are only applicable for tomatoes bound for processing. In many cases, the damage to FV bound for processing is unseen and does not impact the price of the final product (Sarig et al. (2000); Huffman (2012)). Damage in fresh FV markets is more serious as blemishes are fully visible to the consumer and make it them difficult to market. Though some growers sell crops for processing, this is not the norm for farms in the Midwest. Approximately 2% of FV farmers in the Midwest grew tomatoes for processing and about 93% of Midwestern tomato producers sold exclusively to fresh markets in 2007 according the Census of Agriculture (USDA (2012)).

Shake systems are another advancement in FV mechanization. Farmers use these systems to aid in harvesting various bush and tree crops. These machines have arms that firmly grasp limbs of a bush or tree and vigorously shake it to dislodge fruits or nuts. There are two types of shake systems, shake-and-drop systems allow the produce to fall to the ground to be collected by workers and shake-and-catch systems "catch" the falling produce on angled slopes that the surrounds the plant. Shake-and-catch help reduce damage to falling fruit from the impact. These systems have had success in the processed orange industry in Florida but are most applicable to and used in Midwest for nuts, apples, and small berries, particularly in Michigan. Growers in Michigan currently use catch systems to harvest raspberries, blueberries, and more prominently tart cherries bound for processing. These types of systems are quite effective at reducing required labor since it reduces the need for handpicking and the associated ladder work. However useful, these systems may also damage the fruit or trees from the abrasive shaking. This is of particular concern to fresh FV producers since aesthetic imperfections to fresh produce drives down its price, a concern not shared by processed crops such as tart cherries or wine grapes (Huffman (2012)).

FV growers have used diggers to harvest FV crops for many years. Potato diggers were the first used in the 1900s. These diggers extract below ground crops such as potatoes or carrots by scooping under the crop and elevating it onto a moving sieve to remove excess soil and distribute it into a hopper or behind the digger for removal. Since the mechanism digs underneath the root crop there is little aesthetic damage and both fresh and processed FFV growers can use diggers in the enterprise. Like today's tomato harvesters, modern diggers can have electronic optical sorting systems to further reduce the workers needed to harvest potatoes (Huffman (2012)).

Harvest technology has greatly increased efficiency and cost savings for FV farmers, however their scope is quite limited and many crops still need hand harvesters. For this reason it is worth discussing other technology that is available to mainstream FV farmers in the Midwest. Today's FV growers use a variety of tilling strategies that. Much of the research from HortTechnology involves conservation tilling, tilling with a plow or disk, or no-till systems. Conservation tilling seems to be getting the most attention from the horticultural community. This style of tilling pertains to soil cultivation that leaves at least 30% of the soil's surface is covered with residue after planting the next crop. Conservation tilling is an intermediate option between no-till and tilling with a plow or a disk (MDA(AG) (2013)). Conservation tilling saves time versus regular tiling because the soil is not tilled as intensely. It also saves water because it is better able to penetrate the topsoil and move through the beds. Since conservation tilling retains some of the soil's organic residue it also helps improve the soil. Because this residue is kept in the soil, conservation tilling also reduces the temperature of the soil since there is not as much black matter present. This may delay the development for warm season crops and impact yields (Hoyt (1999)). Conservation tilling systems require certain machinery to create beds and plant. No-till planters for corn or beans are usable for crops with larger seeds and standard transplanters can be planted in the seedbed. Small seedbeds can be prepared using a rotary tiller with only the middle tines or with special implements with tilling and cutting coulters and rolling baskets to incorporate matter and break up dirt clumps (Hoyt et al. (1994)). Many walk-behind tillers would also have the workable width to prepare these beds.

Plastic mulch is another innovation in fruit and vegetable production. Plastic mulch is a sheet of plastic that a farmer lays, usually by a machine called a layer, over beds to help retain moisture and heat and control weeds. Plastic mulch saw its first commercial use on farms in 1939 in the form of polyethylene sheets. To plant on plastic mulch, it is punctured and seeds or transplants are placed in the bed below the hole. Most mulch today comes in three colors: black, white, and transparent. Black is the most popular color of plastic mulch since it absorbs more light and transfers heat to the soil by convection. Using plastic mulch in conjunction with drip tape, thin hoses laid under the mulch and connected to a water line, help with water efficiency significantly. Because water cannot evaporate as easily through drip tape, water is more directly applied to the plant, this system reduces water consumption by 45% relative to overhead sprinklers. This system dramatically increases yields achieving up to three times the normal yield of un-mulched crops. Most weeds are unable to survive under plastic mulch since light only enters the mulch under the holes used during planting (Lament (1993)). This means these systems could considerably reduce the amount of labor time devoted to weeding. Another FV irrigation technique is drip irrigation. With drip irrigation systems, hoses with openings at given lengths are placed above the center of seedbeds and drip water over the plants. These systems are effective since they directly apply water to the beds themselves reducing waste and runoff within and between the bed rows. Drip systems are also a way to apply fertilizer before crops are planted and throughout its development a task known as "fertigation" (Huffman (2007)).

1.3 Research Goals

The past research offers useful information but there are significant gaps to fill in the analysis of midwestern growers. Past literature gives a formal framework for examining mechanization of farms in general and a general description of machines that FV growers currently use. However, midwest FV research is noticeably scarce as is research examining the technological use among farms. FV farms arguably have more options with respect to what they produce and the manner in which they produce than a "typical" midwestern farmer. Every farmer that grows row crops needs, at a bare minimum, a planter, a sprayer, and a combine to be competitive. For these crops, the days of planting by hand and harvesting by sickle have long since past. This technological advancement has not been as prominent in the FV industry as a whole. Hand harvesting is still a common practice for many FV crops. Other tasks such as weeding and planting now have mechanical alternatives but mechanical adoption is far from universal. Midwestern farms are generally smaller and produce fresh FV for direct marketing versus commercial production for processing. As figures 1.2 and 1.1 show, there are differences but also striking similarities between the distribution of vegetable farms inter- and intra-regionally. Both figures show that many farms in and outside of the region grow vegetables on one to five acres but tend to diverge as production increases. This poses the questions of why smaller farms are more commonplace in the midwestern FV industry and if growers are willing to expand how best to make these expansions economically feasible. If there are location-specific factors such as higher relative wages or labor availability that are constraining expansions, regional research must be conducted to verify these claims, a job that this paper is tasked with. Since machinery can be purchased outside of the region and has the potential to offset labor costs, much of the analysis will examine the potential of machinery for farmers wishing to expand their FV enterprises.

To meet these larger goals, we will focus on a small set of objectives to better understand what it means to produce FV and expand production in the Midwest, specifically in the state of Iowa. The first objective is to provide a general description of FV farms in the Midwest, specifically those in Iowa. This description includes farm size, years of experience of the primary owner, relative levels of machinery and labor they use, what they grow, how production varies over the season, what other activities take place on farms, and how farmers market output. The second goal is to determine how these farm characteristics influence a farmer's decisions, specifically with respect to labor and machinery and why. Because expansions are of interest, a third objective is to examine how and why expansions take place on midwestern farms and the consequences of these expansions. FV farm expansions can take many forms including adding a new crop, expanding existing crop acreages, and extending the season. These expansions can have different consequences that need to be addressed and put into context before making recommendations for farmers wishing to expand. The final objective is to produce a model to assist farmers in their expansions with the help of these findings.

CHAPTER 2. METHODS, DATA, AND THEORETICAL FRAMEWORK

2.1 Introduction

No two farms are identical and fruit and vegetable farms are no exception. Weather effects, terrain, and soil composition can vary between farms located only a few miles apart. Arguably differences among fruit and vegetable farms can especially impact their ability to use machines since certain crops do not have mechanical alternatives to hand labor and such farms tend to operate on relatively smaller scales. Certain crops such as asparagus do not need to be planted each year but have labor intensive harvests. Other crops that are common to orchards take several years to begin producing, are practically immobile after they are planted, and require special tasks such as pruning during the offseason. Because of the potential for a highly heterogeneous population, a classic statistical approach may not be appropriate for examining such things as degrees of economies of scale or scope of fruit and vegetable enterprises. To address these and similar production questions, our approach must be receptive to the contextual differences between enterprises. A lack of research and subsequent data sets for midwestern fruit and vegetable farms also presents challenges for examining the production decisions.

To create a usable data set, we conducted both a survey and a case study. The survey took place over the first quarter of 2012 during the fruit and vegetable conference season. To gain perspective on the context sensitive aspects of the farms, a case study was conducted. The case study interviews were conducted over January and February of 2013.

2.2 Survey Methods and Data

To gather information on the farming community as a whole, a survey was conducted over the first quarter of 2012. This survey asked midwestern fruit and vegetable growers about their current machinery ownership and use, labor requirements, interest in machinery sharing, and machinery needs relevant to expansion. A blank copy of the survey can be found in in the appendix. Surveys were collected from attendees at the annual conferences of three grower organizations in early 2012: Practical Farmers of Iowa (PFI), Iowa Fruit and Vegetable Growers Association (IFVGA), and the Midwest Organic and Sustainable Education Service (MOSES). Growers that agreed to participate were entered into a random drawing for a free membership in the grower organization of their choice. A few additional surveys were collected at other local or regional grower workshops during this time period. Producers submitted a total of 44 completed surveys.

Of the 44 farmers surveyed, 39 were in Iowa, four were in Wisconsin, and one was in Minnesota. The 39 Iowa farmers came from 24 counties, mainly in the eastern, central, and northern sections of the state (Figure 2.1). We grouped the locations of Iowa's respondents into north, east and central regions (Table 2.1). Approximately half of the 39 Iowan respondents are located in the central region. On average, farmers in the northern and central regions have fairly similar operations while farmers in the eastern region devote fewer acres to growing fruits and vegetables and more to other activities such as conventional row crops. Eastern region growers had less experience growing fruits and vegetables and smaller fruit and vegetable operations on average (Table 2.1).

Table 2.1: Average Iowa Respondent Characteristics by Region

Region	Central	Eastern	Northern
Respondent Counts	20.0	6.0	13.0
Average Fruit and Vegetable Acres	8.3	4.6	9.3
Average Non-Fruit and Vegetable Acres	212.4	271.7	142.7
Average Annual Employment (Workers)	3.4	2.6	2.9
Average Produce Experience (Years)	11.7	7.1	11.1

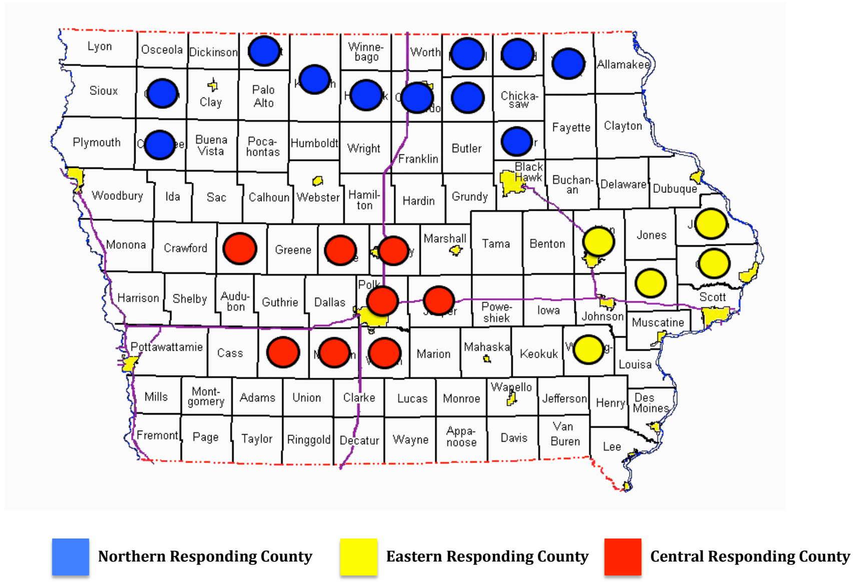

Figure 2.1: Counties of Surveyed Farms

2.3 Case Study Methods and Data

A multi-case study was also conducted. The goals of the case study were to describe the characteristics of the farm and answer questions concerning machinery acquisition in the context of these characteristics and expansions (Figure 2.2). Although the survey was helpful in describing the farms and the machinery decisions to an extent, it was not especially useful for answering these "how" and "why" questions. Surveys show trends among the fruit and vegetable growing community but do not provide any of the motivating factors behind these observed decisions. Questions like "How do farmers decide what machinery to purchase?" and "Why do farmers invest in machinery for their farm? " are directly asking for such motivations. In his book, Robert Yin (2003) provides justification for case studies as a method for analyzing such contextual questions especially when the researcher has little control over the events being studied (Yin (2003)). Several other researchers echo these recommendations for case studies in agricultural economics directly through methodological recommendations to fellow researchers and indirectly by using them in their own research (Kennedy and Luzar (1999); Westgren and Zering (1998); Bitsch and Yakura (2007)).

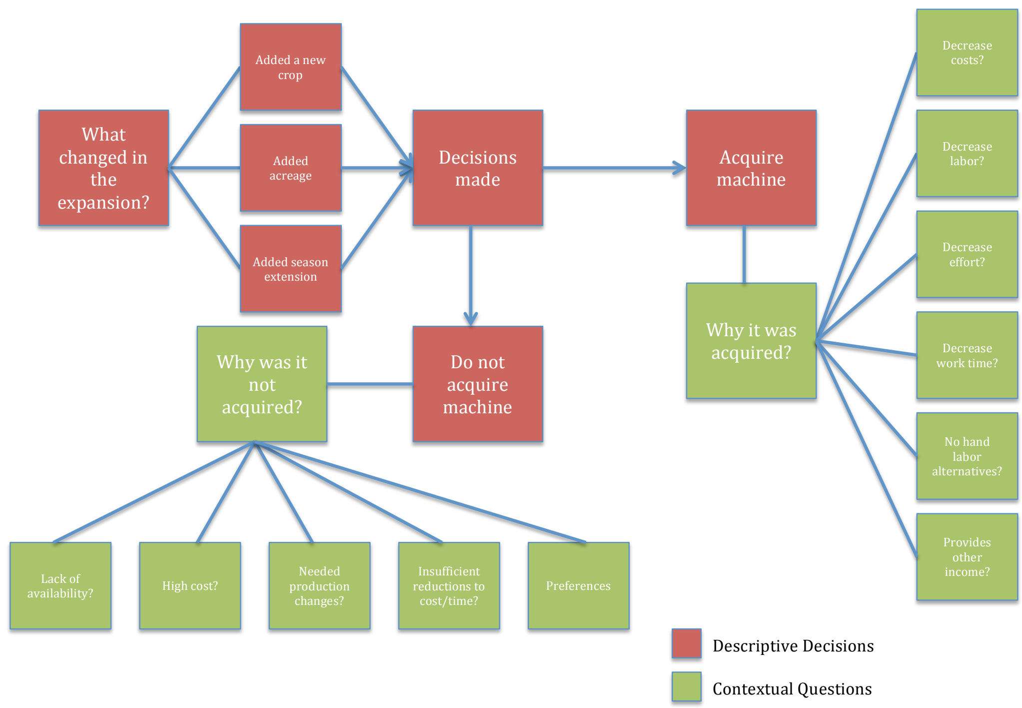

Figure 2.2: Qualitative Data Outline

There are several types of case studies to choose from. Because there are many farm-level factors that may impact the suitability of mechanization versus hand labor, a multi-case study was conducted to compare and contrast responses from a diverse set of growers. Since the goals of the study involve the farmer's input management decisions with special emphasis on expansions, the relationship between individual growers and their farms served as the study's unit of analysis. These relationships were examined by asking farmers about their farms, their expansions, and their farm management practices. With the assistance of Linda Naeve, Craig Chase, Darren Jarboe, and Margaret Smith of Iowa State University's Extension and Outreach Service, a group of six farmers was selected from a set of criteria based upon the recommendations of the extension personnel and the literature (Table 2.2). The ultimate justification for these criteria was to create a set of farmers that had experiences to report and were diverse enough to provide a contextual analysis of what can be a diverse profession. In addition to these criteria, efforts were made to include farmers that marketed in different ways and farms with various amounts of fruit and vegetable acreage.

After establishing a set of criteria, with the help of these extension agents, a list of farmers within the state of Iowa was constructed. Prospective farmers received telephone calls to explain the purpose and requirements of the study and to query their willingness to participate. The phone inquiry continued until a group of willing farmers that matched the criteria quotas was complete. After the initial phone inquiry, the selected farmers received a verification letter by mail describing the time, location and terms of the interview. These terms stipulated that participants would receive $50 in compensation for their participation, any question asked during the interview could be refused without penalty to compensation, and gave them the opportunity to remain anonymous. Participants then needed to sign, date, and state their preference of being identified on the letter and submit it before the interview began. They received a copy of the letter at the interview. Each farm was given a number from one to six to maintain anonymity for participating farmers wishing to remain anonymous.

Interviews took place over January and February of 2013 since this is typically an idle period for fruit and vegetable farms. Interviews were open-ended so farmers could bring up important points but a set of questions ensured that interviews kept focus on the major themes of the research. The set of questions, located in the appendix, asked for the farm's characteristics, marketing techniques, and the context of labor and machinery decisions that the literature and extension agents suggested (Tables B.1, B.3, B.4, B.5). Interviews were audio recorded and later transcribed. These qualitative data were then imported into qualitative research software (RQDA[1]) and analyzed by computer. The analysis of respondent data begins with brief descriptions of each of the six respondents in the next section.

2.4 Theoretical Framework

Basic microeconomic production theory can help illustrate the core of the goals of this research. In production, a set of inputs is brought together to yield an output. The mechanism that assigns output to this set of inputs ($\mathbf{X}$) is called a production function ($f(\mathbf{X})$). There are likely many combinations of inputs that can produce a given level of output. This is because in many instances, inputs like labor hours (L) and machines (K) can be traded off. These tradeoffs

[1] http://rqda.r-forge.r-project.org

posit an important question, what are most restrictive combinations of inputs that are able to produce a given level of output; this is the concept of an isoquant function. If we make the reasonable assumption that each input exhibits positive but diminishing marginal productivity, the isoquant curve will be the lower boundary of convex set of inputs (Figure 2.3). The slope of the isoquant curve is called the marginal rate of technical substitution (MRTS). This represents the labor-capital tradeoff explicitly. Since output is fixed on an isoquant, the MRTS represents the amount of capital that can be traded away by adding an additional unit of labor while still producing a given level of output.

For a more rigorous and contextual definition of MRTS, consider a farm that produces vegetables using labor hours (L), and machinery (K). The farm's production function will be $f(L,K)$ where $\frac{\partial f}{\partial L}, \frac{\partial f}{\partial K} > 0$ and $\frac{\partial^2 f}{\partial L^2}, \frac{\partial^2 f}{\partial K^2} < 0$. In other words, increasing L or K will increase production but with diminishing effect as their respective use increases. The MRTS is the tradeoff of labor versus machinery that is necessary to keep production constant ($Q_0 = f(L,K)$). If a firm were to decide to alter its input vector while maintaining the same level of production (remaining on the isoquant), these input changes must result in zero change to output (Equation 2.1). This implies that in order to maintain production while being as efficient as possible, the firm must use less labor as machinery increases and vice versa (Equation 2.2). If the farm is currently using a great deal of labor relative to machinery (L_0, K_0) and is considering adding machinery, the MRTS with this input vector will dictate a relatively large reduction in labor for a given increase in K. This is because of the second order derivative of the production function. At (L_0, K_0), the marginal productivity of K is far higher than the marginal productivity of L meaning that a small increase in K would allow the farmer to displace labor in relatively greater amounts. If a farmer further mechanizes production, the relative marginal productivity of machinery versus labor will shrink leading to smaller reductions of labor for a given change in machinery (Figure 2.3).

$$\frac{\partial f(L,K)}{\partial L}\Delta \mathrm{L} + \frac{\partial f(L,K)}{\partial K}\Delta \mathrm{K} = 0 \tag{2.1}$$

$$\Rightarrow \frac{\Delta K}{\Delta L} = -\frac{\frac{\partial f}{\partial L}}{\frac{\partial f}{\partial K}} = -\frac{MP_L}{MP_K} = MRTS \tag{2.2}$$

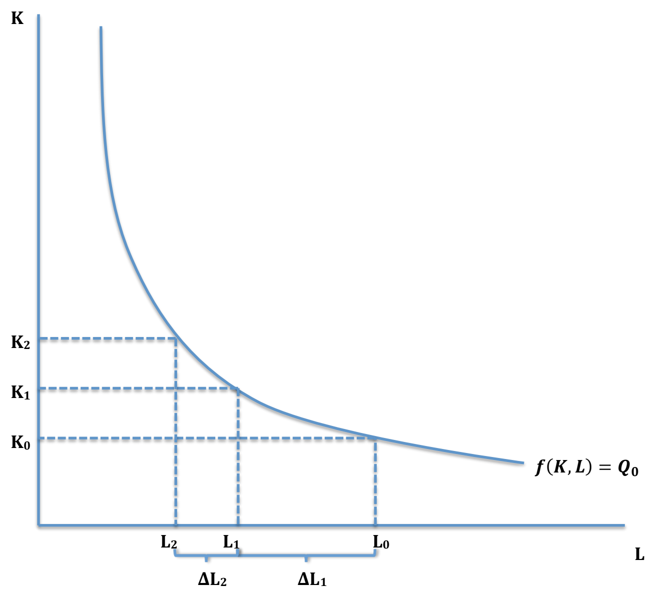

Figure 2.3: Isoquant Illustration

The goal of most firms is to maximize profits (π). This incorporates two functions, a revenue function and a cost function. If we consider only labor and machinery inputs the revenue function in its simplest form is the product of the output produced ($f(L, K)$) and the price of the output (p). In perfectly competitive markets, prices are assumed to be exogenously determined by the market. The cost function is a sum of the products of the inputs (L, K) and their respective prices (w, r) that are also exogenously determined. The difference between the revenue and the cost function is the profit function.

$$\pi = f(L, K) \times p - wL - rK$$

The profit function is maximized when the first derivative of the profit function for each input is equal to zero and it passes the second derivative test of a maximum. The dual approach to solving the profit maximizing firm's problem is to consider how to minimize costs for a given level of output (Chambers (1988)). Under this method, the cost function incorporates the inputs and the isoquant's level of output ($C(L, K, Q_0, w, r)$. Using a Lagrangian, this will describe the relationship between the optimal level of each input and the prices for each input for a given level of output (Q_0). The first order conditions of the Lagrangian show that the firm is minimizing costs when the ratio of the input prices is equal to the ratio of the marginal productivity of the respective inputs (2.6). If this were not the case, the firm would not be minimizing cost for its given level of output.

$$min_{L,K}\mathcal{L} = wL + rK + \lambda\left[Q_0 - f(L,K)\right]$$

$$\frac{\partial \mathcal{L}}{\partial L} = w - \lambda f_L = 0 \tag{2.3}$$

$$\frac{\partial \mathcal{L}}{\partial K} = r - \lambda f_K = 0 \tag{2.4}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = Q_0 - f(L,K) = 0 \tag{2.5}$$

$$2.3 \ and \ 2.4 \Rightarrow \frac{w}{r} = \frac{f_L}{f_K} \tag{2.6}$$

The firm faces a budget constraint on how much it can spend on inputs (B). This means that $wL + rK \leq B$. Under the dual approach, (B) is determined through the minimization process. This constraint can be illustrated on the (L, K) axis along with the isoquant from the previous figure (Figure 2.4). The area underneath the budget constraint curve represents all the combinations of the inputs that the firm can afford given the budget constraint. Notice that the budget constraint curve has a slope of $-\frac{w}{r}$ in the plane. This slope represents the rate that a farmer is able to trade machinery for labor for a given budget. Recall that the MRTS is the rate that a farmer is required to trade machinery for labor if production is to be sustained. This means that at the tangency point (L*,K*) the firm is both able to purchase the inputs required to produce (Q_0) and minimizes costs by conforming with the first order cost minimization condition. Consider what happens to (B) if wages increase from w to w_1. This would mean that the farmer, given the current budget, can not afford as much labor ($\frac{B}{w} > \frac{B}{w_1}$) and the budget line becomes more steep represented by the red line in figure 2.4. This reduces the options of inputs that the farmer can afford with the budget (B). To minimize the cost of producing Q_0, the farmer must spend more on inputs to conform to the cost minimization ($B_1 > B$). Because labor has become relatively more expensive, the profit maximizing combination of inputs will increase machinery and decrease labor $(L^1, K^1) : \; L^1 < L^* \; and \; K^1 > K^*$. The same is true if the rental rate of machinery (r) rises to r^1. This is shown in yellow in the figure. In this case, the budget will have to be increased to B^2 to maintain production. Due to the increase in the rental rate of machinery, the farmer will use less machinery and more labor $(L^2, K^2) : \; L^2 > L^* \; and \; K^2 < K^*$.

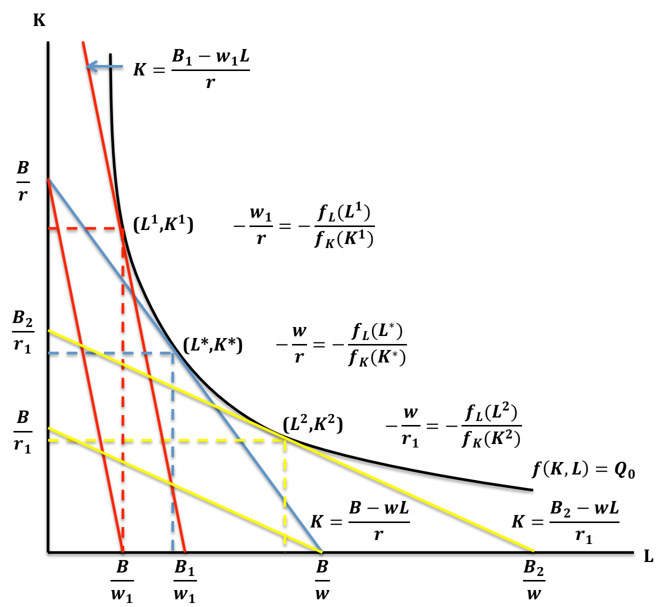

Figure 2.4: Cost Minimization on an Isoquant

Since farm expansions are of interest to the research, a natural question to ask is what happens when a farm chooses to increase production? Given that input prices stay the same for our example, we will consider that the budget of the firm increases to (B_1) and the target quantity rises to (Q_1). These will shift both the budget constraint curve and the isoquant to the right. The form of the cost function is determined by prices that are relatively observable, but farm-level technology impacts its shift. This technology, described by the production function, is somewhat ambiguous. Technology of the firm may evoke lumpy inputs, increasing returns to scale, decreasing returns to scale, etc. and impact the magnitude and the trajectory the isoquants move in as quantities increase (Figure 2.5). Some inputs may become relatively more crucial at higher levels of production. The double starred isoquant represents technology where capital becomes relatively more important for producing more at minimizing costs. The single starred isoquant represents the same phenomena with respect to labor. This figure illustrates the core of the goals of this paper pertaining to expanding farms. If machinery indeed becomes more important as expected what is the optimal cost minimizing path of increasing production? To what degree do farmers trade labor for machinery as they expand production?

There are several hypotheses for FV farm input dynamics throughout expansions. Some farms may have better access to a cheaper labor force. Farmers that have large families or run a CSA that requires members to contribute labor may employ more labor as they expand. CSAs also must maintain production throughout the year to fill the schedule of their shareholders. This leads to sequential plantings and harvesting throughout the year and prevents machinery from working the farm's entire acreage at a given time. On the other hand, CSAs give the farmer certainty in output and in cash flows. CSA members often purchase their shares before the season begins so a farmer may be better able to purchase machinery up front. Wholesale farmers may opt to use more machinery as they expand because they grow an acreage that is not as fragmented over several crops. This may make machine purchases more feasible as they are better able to take advantage of economies of scale with respect to machinery. Some crops are more labor intensive than others. Farmers growing root crops are able to harvest mechanically through diggers where crops like strawberries or peppers have no such option.

Survey analysis will use this approach of examining L and K tradeoffs. Inferences can be made with this type of analysis but survey data is not entirely ideal for this type of analysis. Data on output is difficult to collect with a simple survey but acres could serve as an appropriate proxy. The set of farmers in the survey are quite diverse and this makes statistical inference difficult since technology may vary from farm to farm. Among other things they differ by their crop mixes, how they market and their level of output. To address this we will try to categorize farms into similar sets. Labor was not precisely reported in the survey. Many farmers reported their workers in each season but many did not specify the number of hours that they worked in

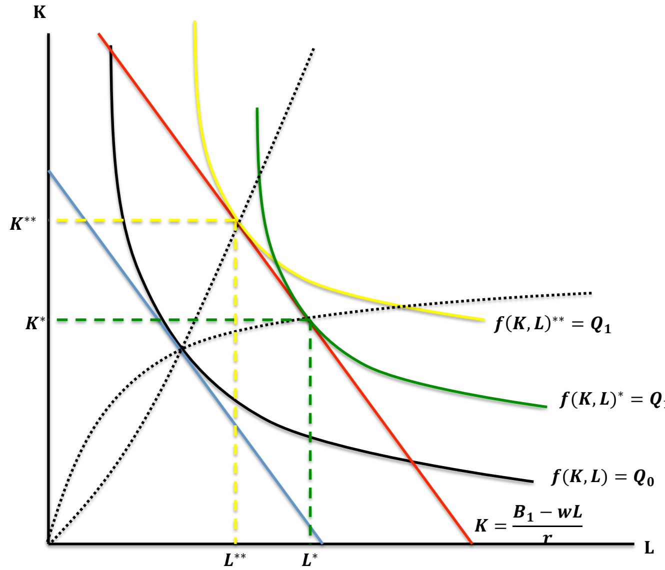

Figure 2.5: Isoquant Shifts with Differing Optimal Paths

each week. For these farms, hours were assumed to be the average number of reported hours in each season. Machinery and labor can be hard to quantify and make input comparisons between the farms. To facilitate cross-input and cross-farm comparisons both labor and machinery were quantified by their price. Most of the farms specified the make and model of their machine fleet. By using for-sale listings, the approximate value for each of these machines can be quantified and adding the sales prices for each of these machines yields the value of each farm's machine fleet. All labor was assumed to earn \$12.85, the average between the median wages of Iowa's agricultural equipment operators and laborers for crop, nursery, and greenhouse collected by the Bureau of Labor Statistics (BLS) that they reported in February of 2013 on their website (BLS (2011)).

Table 2.2: Farm Case Selection Criteria

Criteria	Required Number of Participants	Participating Farms	Rationale
Grower has 8+ years of experience	All participants	(1,2,3,4,5,6)	Experienced farmers are better able to talk about the long-term consequences of their expansion strategies and machinery purchases.
Farm has undergone or will undergo an expansion	All participants	(1,2,3,4,5,6)	Satisfies the unit of analysis condition and the farmer is able to discuss ex post facto and/or ex ante expansion considerations.
Farmer shares equipment or performs custom work	At least one grower	(1,2,4)	Farmers that share equipment or perform custom work may be better be able acquire equipment.
Farmer grows perennials as a primary crop	At least one grower	(1,2,3,6)	Different crops may require special equipment to grow and some crops lack alternatives to hand labor for certain tasks.
Farmer does not grow perennials as a primary crop	At least one grower	(4,5)	
Farmer grows cool-season crops as a primary crop	At least one grower	(2,4,6)	
Farmer grows warm-season crop as a primary crop	At least one grower	(1,2,4,5,6)	
Farm has non-fruit and vegetable enterprises	At least one grower	(1,3,4)	Equipment used for other non-fruit and vegetable enterprises may also be used in the fruit and vegetable enterprise.
Farmer specializes in one or two crops	At least one grower	(3)	If the farm specializes in a few crops, the tasks are more heterogeneous meaning a greater portion of labor saving could result from the purchase of a machine purchase vs otherwise.
Farmer grows a diverse set of crops	At least one grower	(1,2,4,5,6)	

CHAPTER 3. RESEARCH FINDINGS

3.1 Survey Findings

3.1.1 Descriptive Statistics

3.1.1.1 Growing Experience

Years of experience growing fruits and vegetables ranged from one to 34 years. Many farmers are relative newcomers to growing fruits and vegetables. Farmers averaged 10.6 years of growing experience and 20 out of 44 farmers had fewer than seven years of fruit and vegetable growing experience (Figure 3.1).

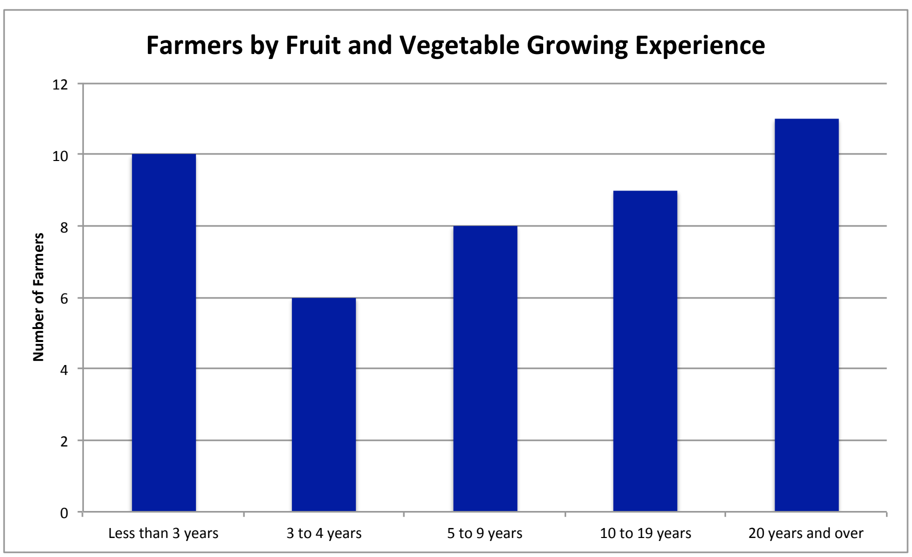

Figure 3.1: Number of Farmers by Years of Fruit and Vegetable Growing Experience

3.1.1.2 Size of Operations

Survey respondents were asked to report the approximate number of acres devoted to fruits and vegetables in their enterprises. Responding enterprises are distinctly divided by size. Fruit acreage ranged from zero to 13 acres with around 45 percent of farms devoting less than half an acre to fruit production while roughly one-fourth (24%) devoted five or more acres to fruit (Figure 3.2). More acreage was devoted to vegetable production, but like fruits, vegetable enterprises were starkly divided by size. Vegetable acreage ranged from zero to 40 acres with over one quarter (26%) of farms growing vegetables on less than an acre and 19 percent growing vegetable crops on over nine acres (Figure 3.3). Combined acreage of both fruits and vegetables was more evenly distributed since, as figure 3.4 shows, over half of the farms produce both fruits and vegetables; total fruit and vegetable acreage ranged from half an acre to 40 acres with an average of eight acres[1]

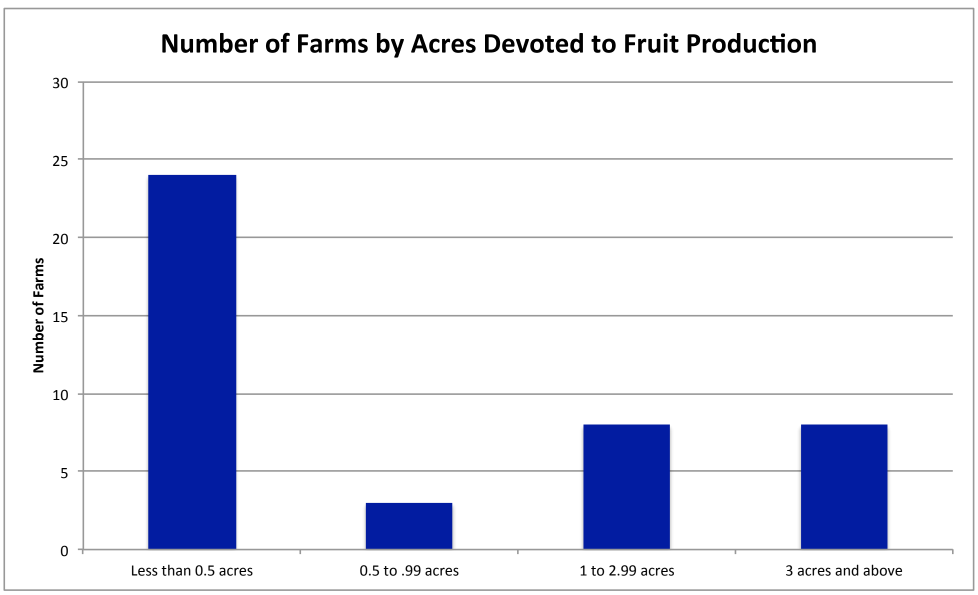

Figure 3.2: Number of Farms by Acres Devoted to Fruit Production

[1]Analysis in this section should be viewed with caution since several farms, including two of the largest vegetable farms, omitted their acreage for fruits despite specifying they grew them. The pie chart in figure 3.4 shows how many farms actually grew fruits/vegetables and is accurate but it is hard to say the same for the other figures.

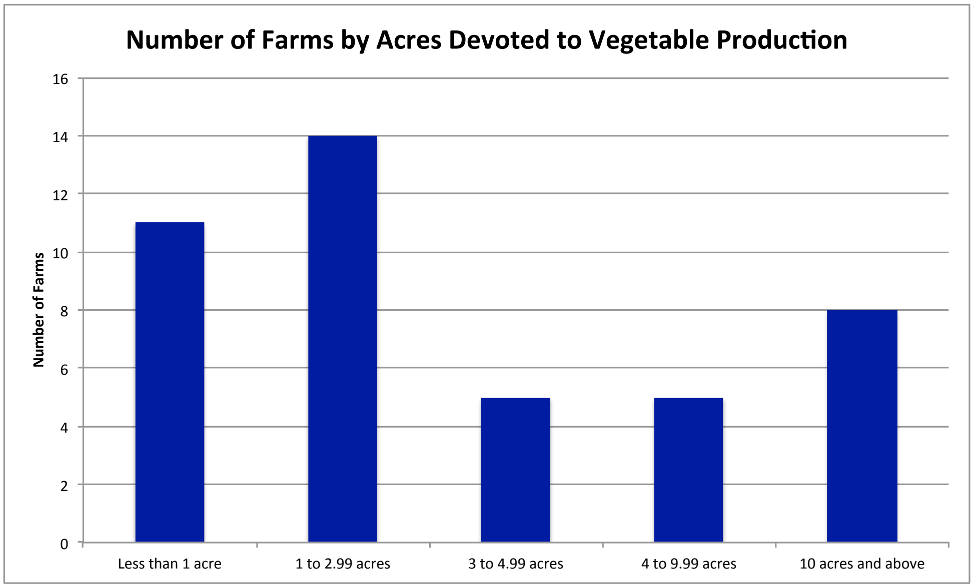

Figure 3.3: Number of Farms by Acres Devoted to Vegetable Production

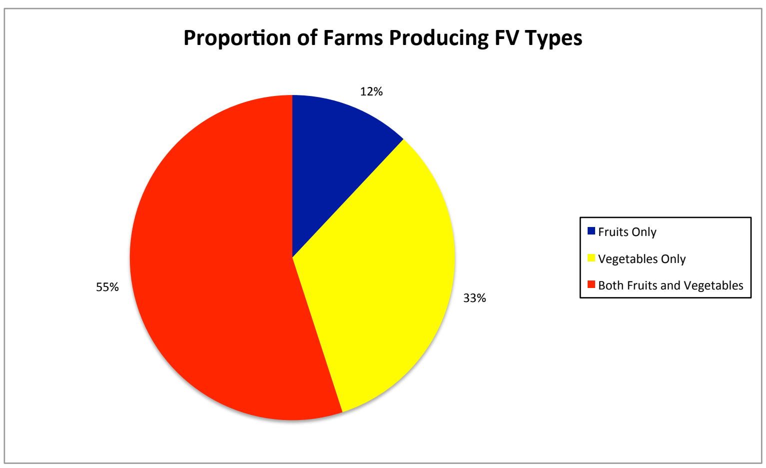

Figure 3.4: Proportion of Farms Producing Produce Types

3.1.1.3 Crop Characteristics

Survey respondents were asked to list the major fruit and vegetable crops raised on their farms. To complement data on seasonal employment and equipment and concisely compare crop specialization, crops were divided into warm- and cool- season types. The addition of these categories permits analysis of how crop selection impacts employment throughout the year. Relative to warm season crops, cool season crops are typically planted earlier in the spring and later in the fall since they grow in cooler climates and are more resilient to frost. Some crop types in this section cannot be easily classified as warm or cool and are incorporated into the "Other" group. Of 43 respondents that reported the crops they grew, 36 grew warm-season or cool- season crops of these types. Table 3.1 specifies the warm and cool crops grown by farms and the proportion of respondents that grew each respective crop. Over 56 percent of respondents grew tomatoes making it the most popular crop in the survey. Approximately one quarter of farmers grew brambles (raspberries, blackberries, gooseberries, etc.) (27.9%), peppers (26%), and strawberries (23%). Over 27 percent of farmers specified they only grew warm season crops (Figure 3.5).

Table 3.1: Number of Farms Growing Crops by Season

Cool Season Crops	Farms	Warm Season Crops	Farms	Other Crops	Farms
Potatoes	4	Tomatoes	24	Brambles	12
Beets	3	Peppers	11	Strawberries	10
Cabbage	3	Sweet Corn	8	Apples	8
Onions	2	Cucumbers	6	Asparagus	5
Brassica	1	Pumpkins	5	Grapes	5
Broccoli	1	Beans	4	Cherries	3
Carrots	1	Egg Plant	3	Garlic	2
Parsnips	1	Melon	3	Plums	2
Radish	1	Squash	3	Apricots	1
Spinach	1	Watermelon	3	Aronia	1
		Sweet Potatoes	2	Blueberries	1
				Chestnuts	1
				Gooseberries	1
				Hazelnut	1
				Nectarines	1
				Peaches	1
				Pears	1
				Rhubarb	1

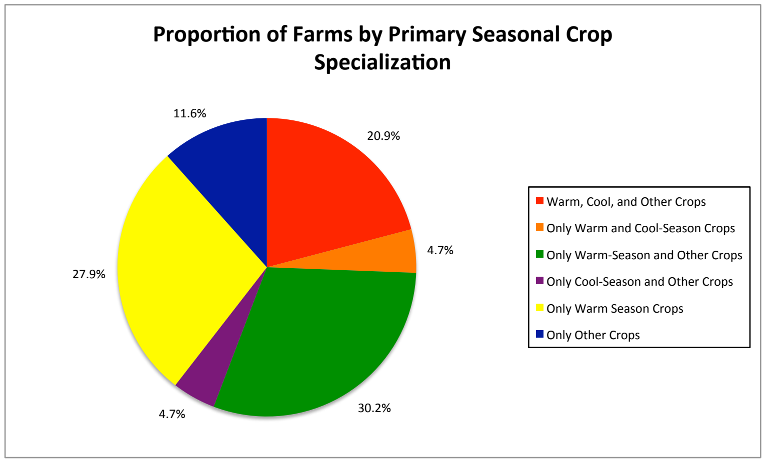

Figure 3.5: Proportion of Farms by Primary Crop Seasonal Specialization

Fruit crops were divided into three categories: perennial tree crops (apples, cherries, pears, etc.), other perennial fruit (raspberries, grapes, strawberries, etc.), and annual fruit crops, primarily melons. Tree crops require three to six years before their investment "bears fruit" (Naeve and Domoto (2000)), whereas most berries and grapes begin producing after one to three years (Relf (2009)). This distinction allows analysis of a farmer's willingness to incur the long-term investment of tree-based perennials versus the relatively short-term investment of other perennials and annuals. Table 3.2 shows the distribution of farmers primarily growing perennial crops by crop type. A majority of farmers in the survey (84%) grew a primary crop that was a perennial and most farmers (75%) grew exclusively non-tree crops (Figure 3.6).

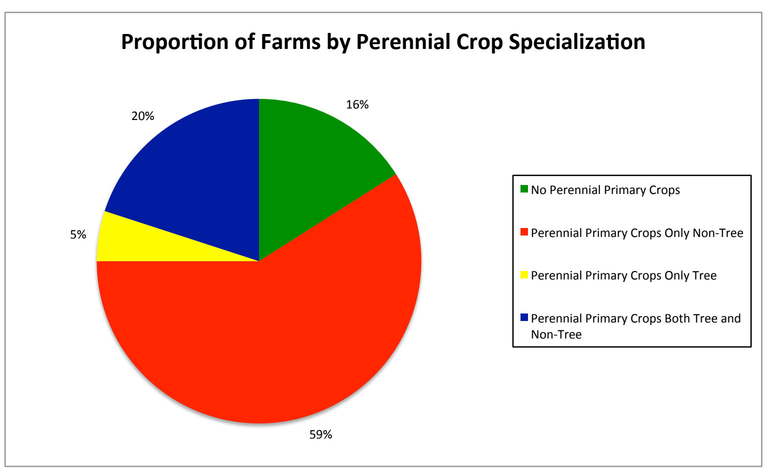

Figure 3.6: Percent of Farms by Perennial Crop Specification

Table 3.2: Proportion of Farms Growing Perennial Fruits and Vegetables by Crop

Perennial Tree Crops		Other Perennial Crops		Annual Fruit Crops	
Apples	18.6%	Brambles	27.9%	Melon	7.0%
Cherries	7.0%	Strawberries	23.3%	Watermelon	7.0%
Plums	4.7%	Asparagus	11.6%		
Apricots	2.3%	Grapes	11.6%		
Chestnuts	2.3%	Garlic	4.7%		
Hazelnut	2.3%	Aronia	2.3%		
Peaches	2.3%	Blueberries	2.3%		
Pears	2.3%	Currants	2.3%		
Nectarines	2.3%	Gooseberries	2.3%		
		Rhubarb	2.3%		

Respondents were asked about land devoted to enterprises other than fruits and vegetable production and about their livestock production. These "other activities" included acres devoted to row crops, pasture land, and forage, and a description and head count of livestock raised on the farm. A majority of farms (59%) possessed acres for these other activities or raised livestock (Figure 3.7). Fruit and vegetable growers that engaged in other activities and raised livestock tended to have more livestock than those that only raised livestock and grew fruits and vegetables.

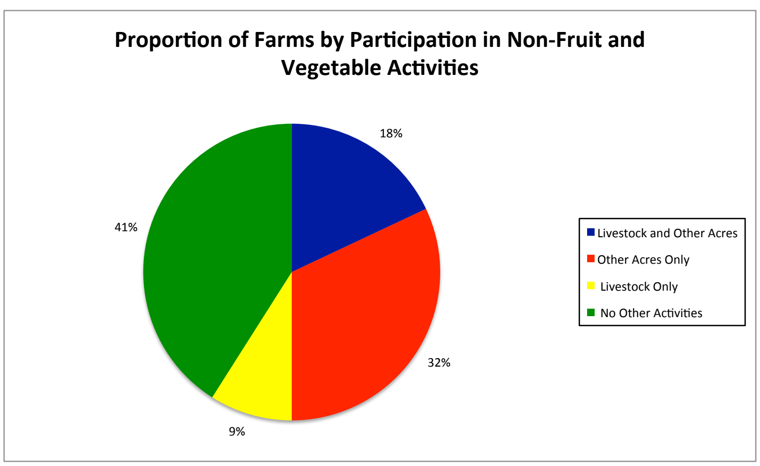

Figure 3.7: Distribution of Farms by Participation in Non-Fruit and Vegetable Production

Farms taking part in "other activities" had on average 368.2 "other" acres and ranged from four to 1,300 acres devoted to other enterprises. Considering all farms in the survey, farmers devoted an average of 184 acres to other activities. To put this statistic into context, we plotted the distribution of fruit and vegetable operations by the proportion of fruit and vegetable acres on the farm (Figure 3.8). Many farms had over 50 percent of total acreage devoted to fruits or vegetables since half of farms had no acres devoted to "other activities"(Figure 3.8). There were only two farms that devoted less than 0.5 percent of their total acreage to produce, both of these farms had over 500 row crop acres which explains why these farms had such a small percentage of total acres devoted to fruits and vegetables since most farms had less than 10 produce acres. On average, row crop acreage as a proportion of the total of other acres falls as FV acreage constitutes a larger proportion of total farm acreage. Conversely, forage acres as a proportion of total other acres rises as the percentage of produce acres rises, constituting a majority of other acres when produce acres make up 25 percent or more of total acreage.

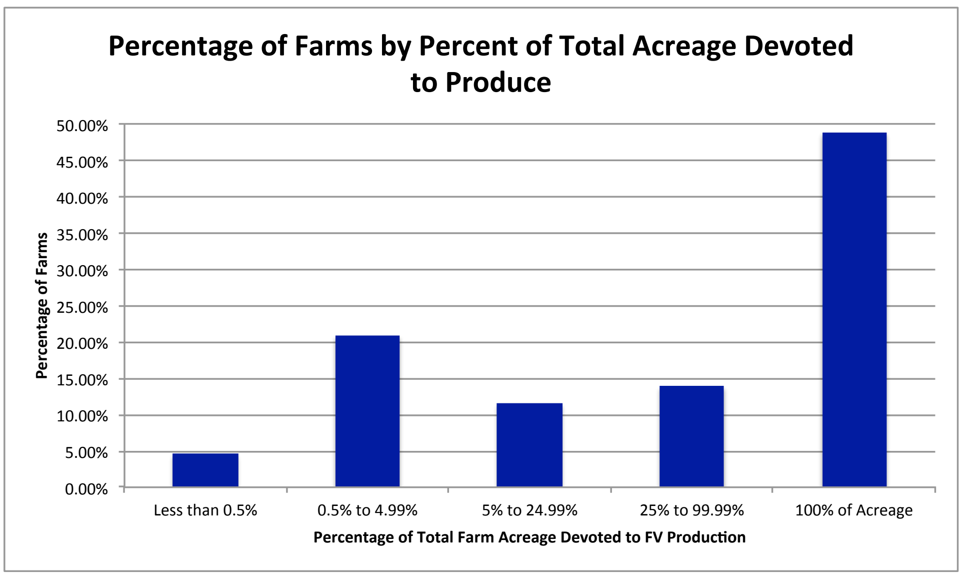

Figure 3.8: Percentage of Farms by Use of Total Acres

3.1.1.4 Employment in the Operations

Survey respondents were asked to report the number of workers they employed in their fruit and vegetable operations each season. This survey defined winter as December, January, and February; spring as March, April, and May; summer as June, July, and August; and fall as September, October, and November. Table 3.3 gives an overview of these findings. Each column contains the percentage of farms that employed the respective number of workers in each season. Not surprisingly, given 84 percent of farms reported at least one warm-season crop, respondents tended to employ more workers over the summer months and fewer workers over the winter months.

Table 3.3: Percent of Farms by Seasonal Employment

	Number of Employees					
Season	0 to 2	2 to 4	4 to 6	6 to 8	8 to 10	Over 10
			Percent			
Winter	52.5	42.5	5.0	0.0	0.0	0.0
Spring	20.0	50.0	10.0	10.0	10.0	0.0
Summer	12.5	45.0	15.0	12.5	7.5	7.5
Fall	20.0	50.0	12.5	12.5	0.0	5.0

Farmers were asked for both full-time and part-time employee counts for each season. The average composition of seasonal employment was highest in the summer and nearly equal in the fall and spring seasons (Figure 3.9). This compliments the previous table showing how many workers the average farm employs each season. On average, the changes in part-time employment account for most of the change in employment over the course of a year and that full-time employment varies little over the course of the year (Figure 3.9).

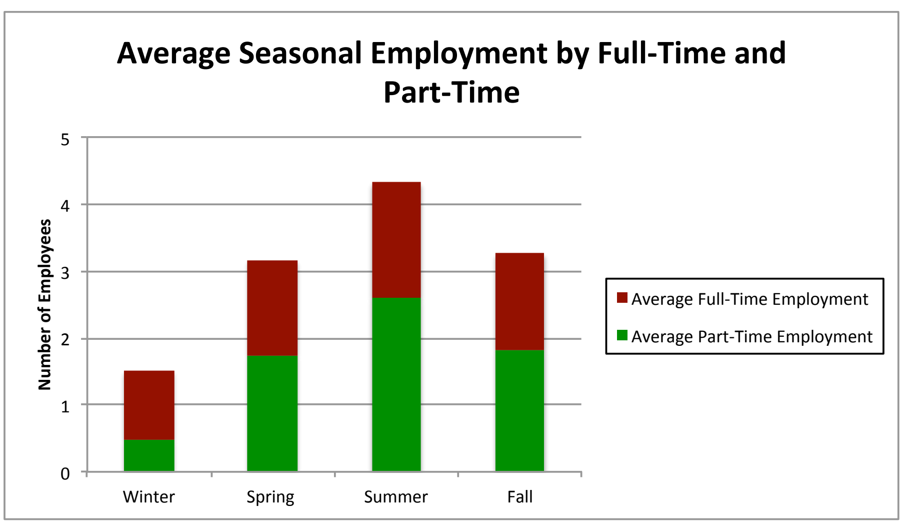

Figure 3.9: Average Seasonal Employment by Full-Time and Part-Time

3.1.1.5 Current Use of Fruit and Vegetable Machinery and Equipment

This section provides a more in-depth look at current machinery use among fruit and vegetable growers. In this section, machinery is divided into 12 categories that are typically used by fruit and vegetable growers. The survey required farmers to specify basic machinery attributes and whether they own, rent, or custom hire machinery. Farmers were also required to rank the five most important pieces of equipment used in their operation. These data help identify the equipment that growers with varying operations view as especially crucial. The top five most used categories of equipment were tractors, tillage, pickup/van, seeders, and cultivators respectively (Figure 3.10).

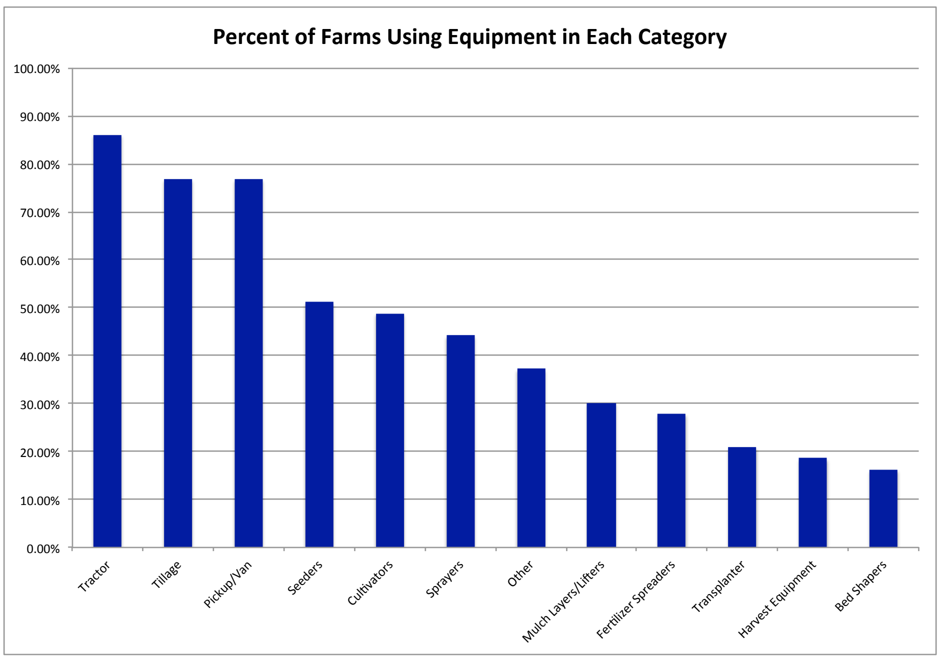

Figure 3.10: Percent of Farmers Using Equipment in Each Category

Farmers were asked to rank the five most important types of farm implements used in their produce operation. These implements were grouped by like types and weighted to calculate an overall "importance score" (Table 3.4[2]). Every number one rank a category received was multiplied by five; every number two rank a category received was multiplied by four, and so

[2]The "Score" is a weighted average of the scores where 1st is multiplied by 5, 2nd is multiplied by 4, 3rd is multiplied by 3, 4th is multiplied by 2, and 5th is multiplied by 1. Eighteen respondents meaningfully ranked equipment. Meaningful rankings constitute no multiple entries in each rank. For instance, respondents ranking more than one category with a "1st" are excluded from this table.

on. Tractors had the highest importance score followed by tillage equipment, and then seeders (Table 3.4).

Table 3.4: Counts and a Weighted Average Score for Respondents That Meaningfully Ranked Equipment

	Ranking					
Ranking/Equipment	1st	2nd	3rd	4th	5th	Score
Tractor	9	7	2	3	1	86
Tillage Eq.	2	4	2	2	4	40
Seeder	1	4	2	2	0	31
Pickup/Van	1	0	3	5	1	25
Cultivator	0	2	3	2	0	21
Sprayer	2	0	1	1	1	16
Mulch Layer/Lifter	1	0	1	2	0	12
Transplanter	0	1	0	2	1	9
Other Eq.	0	1	0	1	3	9
Fertilizer	0	0	0	1	2	4
Bed Shaper	0	0	1	0	0	3
Harvest Eq.	0	0	0	1	0	2

3.1.2 Machinery/Equipment Practices and Needs

This last section of the survey reports the findings of farmers' equipment sharing practices, their custom work, and their plans for expanding production. This section can help show trends between farm characteristics from the background section and their equipment practices. Despite the fact that a relatively small portion (18.2%) of farmers currently shares equipment, 81.8 percent would consider sharing equipment (Figure 3.11). A majority of the surveyed farmers are planning to expand in the next five years (70.5%) and would also consider sharing (Table 3.5).

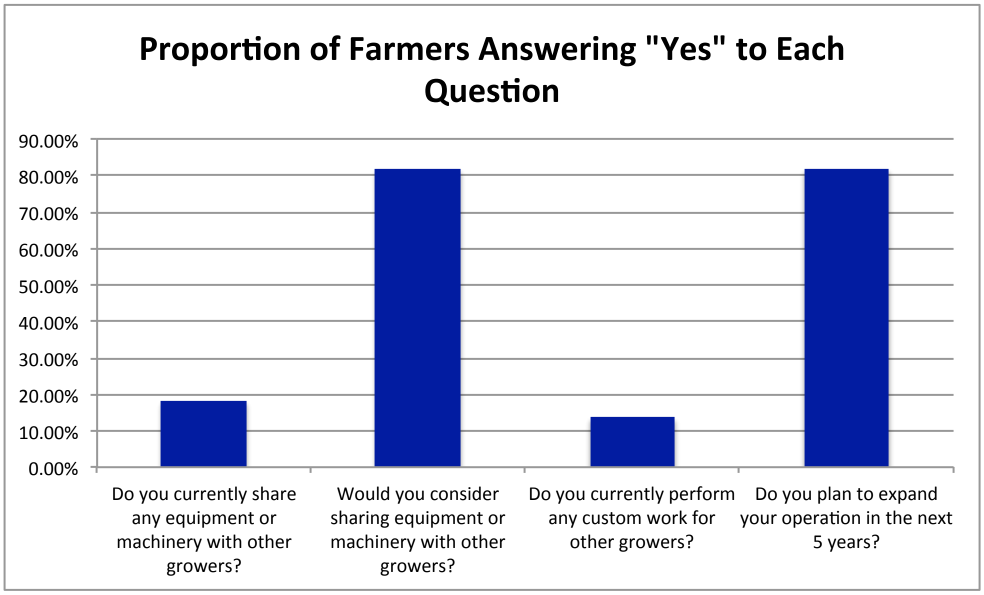

Figure 3.11: Percent of Farmers Answering "Yes" to Each Question

Table 3.5: Percent of Farms Answering "Yes" to Both Questions

Question	Consider Sharing	Perform Custom	Plans Expansion
Currently Sharing	18.2%	2.3%	15.9%
Consider Sharing		11.4%	70.5%
Perform Custom			11.4%

Table 3.6 compares the labor, machinery, and experience characteristics of the total pool of surveyed farms, farms planning to expand, and those considering sharing. We can see that these farms are very similar across these questions. Those farms that are more willing to expand and share tended to have less experience and larger farms.

3.1.3 Input Analysis

Increased farm productivity is one of the primary benefits of employing machinery. Landers estimates that a single tractor can perform the same amount of work as approximately 20 farm laborers, enabling fewer workers to tend the same acreage of land (Landers (2000), p. 1-2). The survey data clearly reflects this relationship (Figure 3.12). There is a sharp and negative correlation between the number of machines used and the annual average number of workers employed per produce acre accounting for over 19% of variability of machinery usage.

Table 3.6: Farm Labor, Machinery, and Experience Comparison Over Question Responses

Farm Characteristics	Total Farms	Farms Willing to Share	Farms Planning to Expand
Avg. Fruit and Vegetable Acreage	6.5	7.8	7.6
Avg. Growing Experience (Years)	10.4	8.8	8.8
Avg. Number of Machines Used	7.0	7.1	6.9
Avg. Annual Employment (No. Workers)	3.1	3.1	3.4

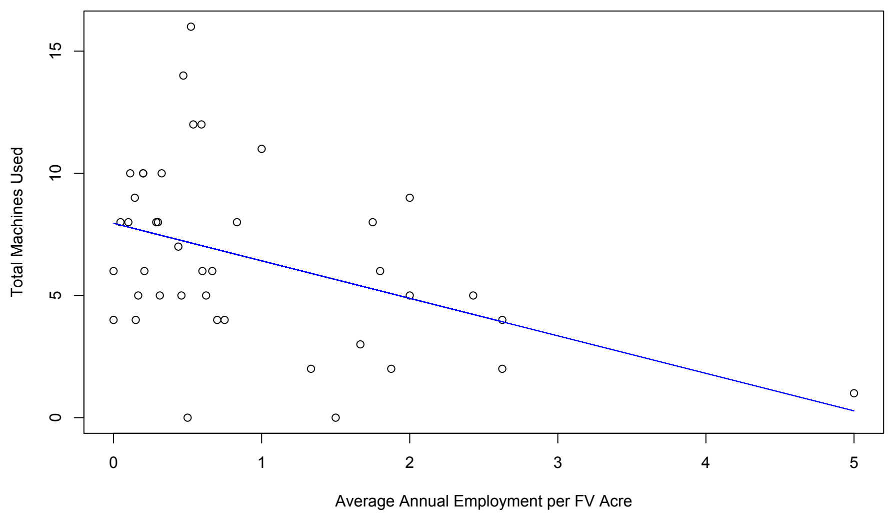

Figure 3.12: Machines Used by Average Annual Employment per FV Acre

Figure 3.12 resembles a Cobb-Douglas production function. In 1928, Charles Cobb and Paul Douglas wrote a landmark paper in economics by describing a production function that had convenient properties of being log-linear, increasing in inputs, exhibiting diminishing marginal productivity for every input, and easily statistically verifiable. This production function shows the relationship between the inputs labor hours (L), capital (K), and a set of other inputs (X) and output (Q) (Cobb and Douglas (1928)). In this form of the production function, α is the output elasticity of labor, β is the output elasticity of capital, γ is the output elasticity of the other inputs, and A is a total factor productivity term.

$$Q = AL^{\alpha}K^{\beta}X^{\gamma}$$

Orazem (1998) shows how Cobb-Douglas technology can be determined empirically for producers with varying levels of output. Taking the derivative with respect to each of the inputs shows that the marginal productivities under this form are proportional to easily observable variables, the average production. This relationship is important since it states that under Cobb-Douglas technology, the marginal product is proportional to the average product. This means that the relationships between average products may be of interest if we want to verify if the FV farms are exhibiting Cobb-Douglas technology. Since output (Q) is in the average product, inverting these terms normalizes these terms creating an empirical isoquant (Orazem (1998)).

$$\frac{\partial Q}{\partial L} = \alpha A L^{\alpha-1} K^{\beta} X^{\gamma} = \alpha \frac{Q}{L} \propto \frac{Q}{L} \tag{3.1}$$

$$\frac{\partial Q}{\partial K} = \beta A L^{\alpha} K^{\beta-1} X^{\gamma} = \beta \frac{Q}{K} \propto \frac{Q}{K} \tag{3.2}$$

$$\frac{\partial Q}{\partial X} = \gamma A L^{\alpha} K^{\beta} X^{\gamma-1} = \gamma \frac{Q}{X} \propto \frac{Q}{X} \tag{3.3}$$

The following plots follow this analysis with the survey data. We do not have access to farm output but we do have each farm's level of FV acreage. The FV acreage will serve as a proxy. Labor and machinery is measured in dollars from for-sale listings to be comparable across farms. Recall that one of the hypotheses was that if a farmer grows many crops on a relatively small piece of land, the farm's acreage would be too fragmented to exploit the economies of scale from labor saving machinery. The acreage for each crop was not specified. As a proxy, crops per acre (CPA) was calculated by dividing the number of primary crops that they stated over their FV acres. In the following figures, the larger circles represent more crops per acre, which is used as an approximation of the level of acreage fragmentation (Figure 3.13).

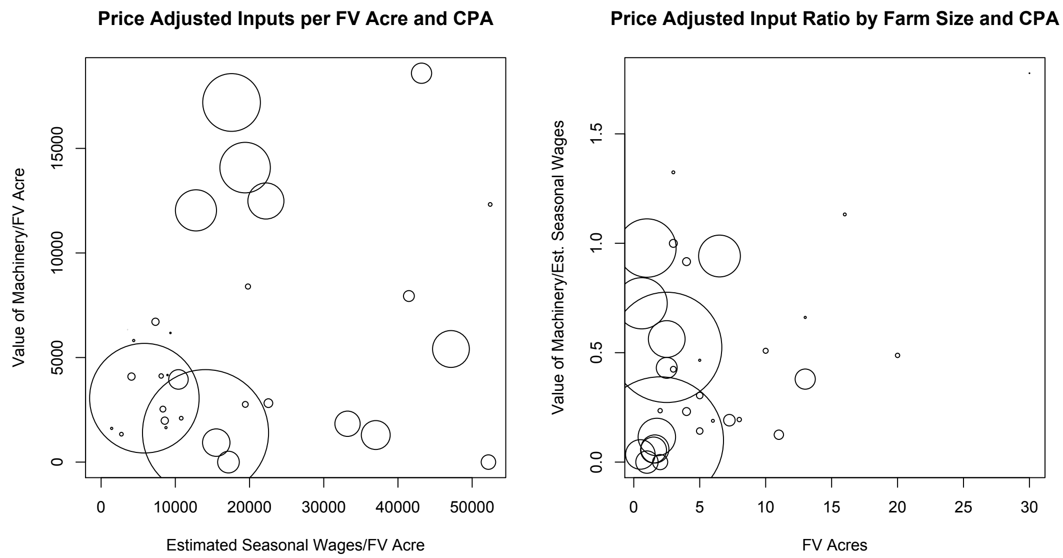

Figure 3.13: Survey Normalized Isoquant and Input Ratio by Size

The data are messy but there are some interesting results. The plot on the right shows plots the level of mechanization relative to labor by the size of the farm. Many farmers produced on less than five acres FV acres. These farms were highly heterogeneous with respect to their inputs but for the most part, they had a higher level of acreage fragmentation. However, growers on larger farms, particularly those that had lower levels of acreage fragmentation, tended to use more machinery relative to labor. This supports the economies of scale and the farm size hypothesis. The plot on the left plots the respective average inputs per FV acre. Recall that $\frac{Q}{L}$ and $\frac{Q}{K}$ are proportional to the marginal productivities of labor and capital respectively. This means that the plot on the left plots the inverse marginal products between labor and machinery. If the survey sample were exhibiting a Cobb-Douglas relationship, we would expect an inverse relationship between $\frac{L}{Q}$ and $\frac{K}{Q}$. We see that there are two groups that have this relationship. The first group is closer to the origin and generally has farms with smaller acreage fragmentation. This first group shows that in general, as farms become more fragmented, farmers tend to use less machinery and labor relative to the size of the farm. The second group is further away from the origin and has higher acreage fragmentation. This could mean that farmers could be facing different technology between these two groups. A natural question to ask is what accounts for the differences between these two groups? The analysis that follows will separate these farms into groups by their characteristics.

3.1.3.1 Farm "Types"

The first part of the analysis will examine farms by "type". The survey did not ask for marketing techniques however some respondents did state that they operated gardens or CSAs. Though much of this diversity among growers may not be explicitly represented in this survey, sorting farms into general categories may capture some of the diversity among the respondents. Information from several respondents looked as though they operated larger gardens or hobby farms. These surveys had a large number of primary crops and had less than one produce acre. Other farmers reported that they operated as a Community Supported Agriculture (CSA) or had over one acre of production with a number of primary crops that are typically associated with a CSA such as tomatoes, sweet corn, beans, broccoli, etc. These surveys were categorized as CSA-type farms. Some respondents reported had more than six produce acres and a small number of primary crops or seemed to have specialty crops that were not associated with a typical CSA such as pumpkins or nuts. These surveys were categorized as Wholesale-type though some of them might be very large CSAs. Some farms did not easily fall into any of these categories reporting unorthodox crop mixes such as potatoes and plums without adequately large acreage to be a typical wholesaler. These farms were called Uncategorized-type farms.

Although this is far from a precise categorization, it may help explain some of the differences in the technology within the sample. The following plots show the relationships by type (Figure 3.14). Perhaps the most revealing results is the difference between the garden and wholesaler types. Garden types tended to use more labor for their size and made up the bulk of the second group in the first plot of figure 3.13. The fact that these growers are not likely growing commercially could explain why they do not look as efficient as many of their profit-motivated counterparts. Wholesale types, with the exception of one outlier, tend to use fewer inputs per acre and mixed nicely with the CSA types. Uncategorized types do not seem to fit with either of the two groups.

We now look at the input ratios and farm size by farm type (Figure 3.15). Garden type farms

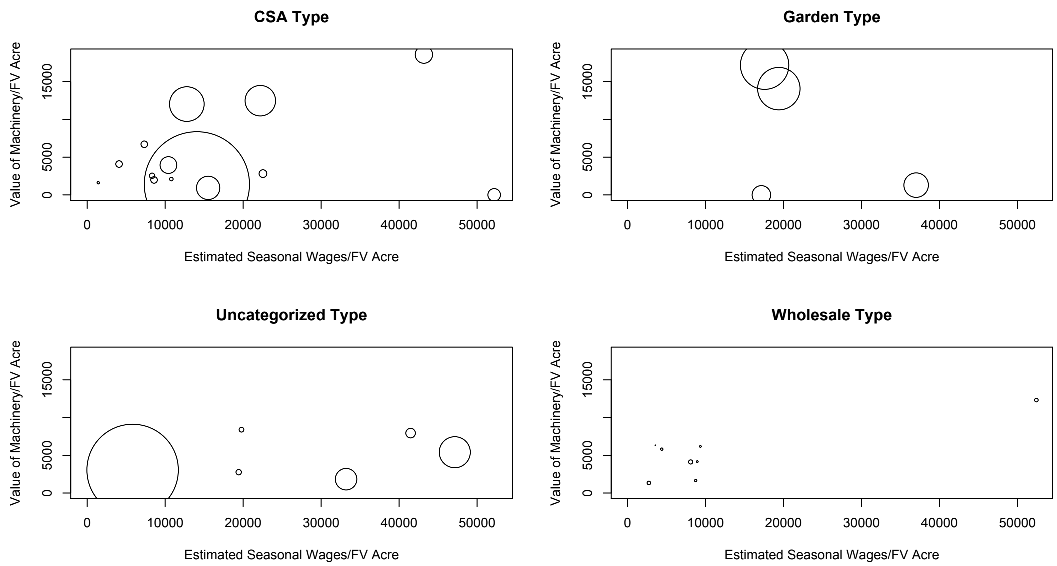

Figure 3.14: Normalized Isoquant and CPA Divided by Farm "Type"

did not differ by acreage but some used more machinery than others. This makes sense because there many small intermediates between hand labor and machinery such as lawn tractors that were reported for these farms. Both CSA and wholesale types exhibited the trends that we would expect and mixed well with one another. The upward trend is particularly apparent for wholesale types and less fragmented CSA types. Farms with higher acreage tended to use more machinery relative to labor. Uncategorized types were highly heterogeneous with respect to acreage fragmentation but generally grew on less than five acres and had similar input ratios. Taken together, there is a clear difference in the technology between the farm types. Garden type farms tended to use more labor and capital relative to their size than most of the other growers in the survey. This categorization is far from precise. CSA type farms tended were highly heterogeneous in both acreage fragmentation and mixed accounted for several farms in the second, input intensive group. However, dividing farms into types shows some of the heterogeneity of FV farmers.

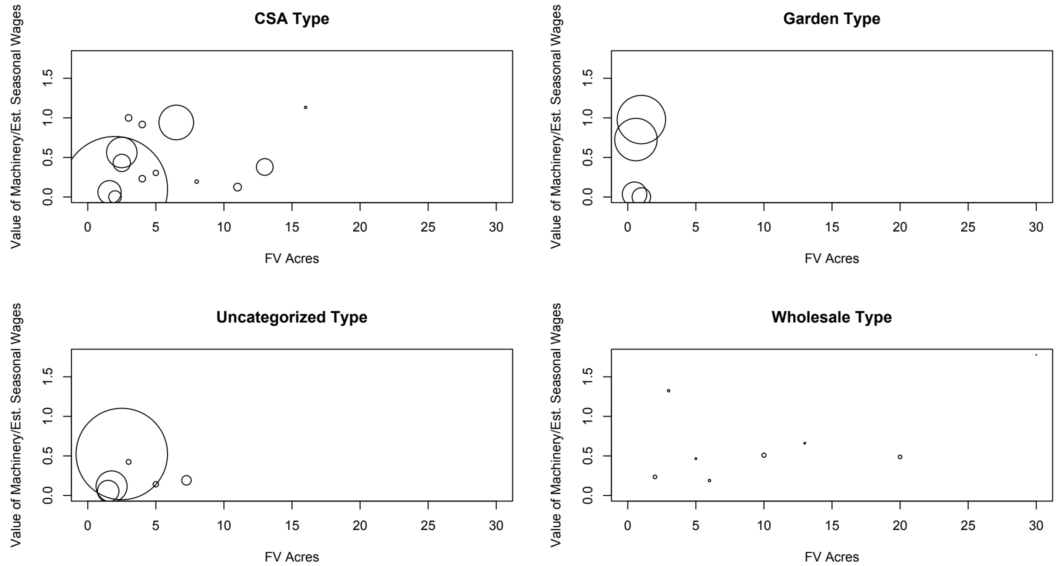

Figure 3.15: Input Ratio, FV Acres, and CPA Divided by Farm "Type"

3.1.3.2 Farmer Experience

In economics machinery is considered a durable asset. Durable assets retain at least a portion of their usability from season to season. Since farmers with more experience have had more time to accumulate a machine fleet, they may use more machinery than their less experienced counterparts. On the other hand, older farmers may be facing retirement and scaling down their machine fleets. Interestingly, with the exception of farmers with 11 to 20 years of experience, farmers with more experience tended to use less machinery and labor relative to the size of the farm (Figure 3.16). Farmers with five or less years of growing experience tend to have more fragmented acreage and are highly dispersed. More experienced farmers tended to drift towards the less input intensive efficiency frontier. What makes the 20 years and over plot interesting is that more experienced farmers are more tightly grouped around the origin despite having a diverse acreage fragmentation. There are a couple of possible explanations for this. FV growers could be deciding to become commercial growers after growing on a garden for several years. It is also reasonable to expect that more experienced farmers are more knowledgeable. A farmer that has grown for many years better informed of the needed inputs on a farm, increasing the productivity.

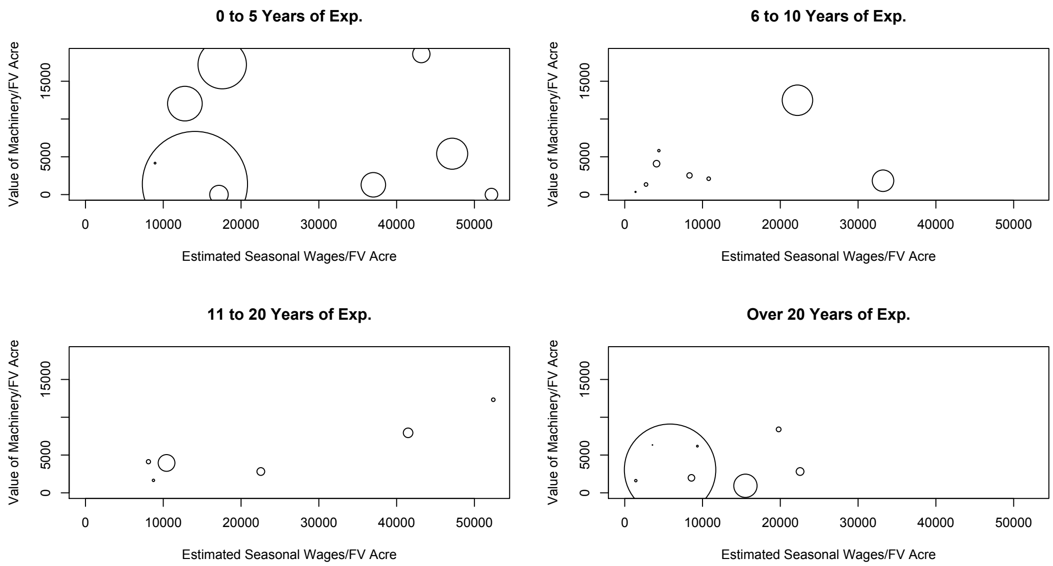

Figure 3.16: Normalized Isoquant and CPA Divided by Farmer Experience

Examining the input ratio and the size of the farm, we see that more experienced farmers tend to have larger farms (Figure 3.17). As the level of experience increased farmers tended to purchase more machinery relative to labor. This could be a consequence of increasing size. Notice that the upward trend seen in figure 3.13 is traced out when as you sequentially add farmers with more experience but many relatively inexperienced farmers growing on less than 5 acres had relatively more machinery. This seems to contradict the durable asset accumulation hypothesis and more experienced farmers simply tend to have larger farms and manage their inputs more efficiently.

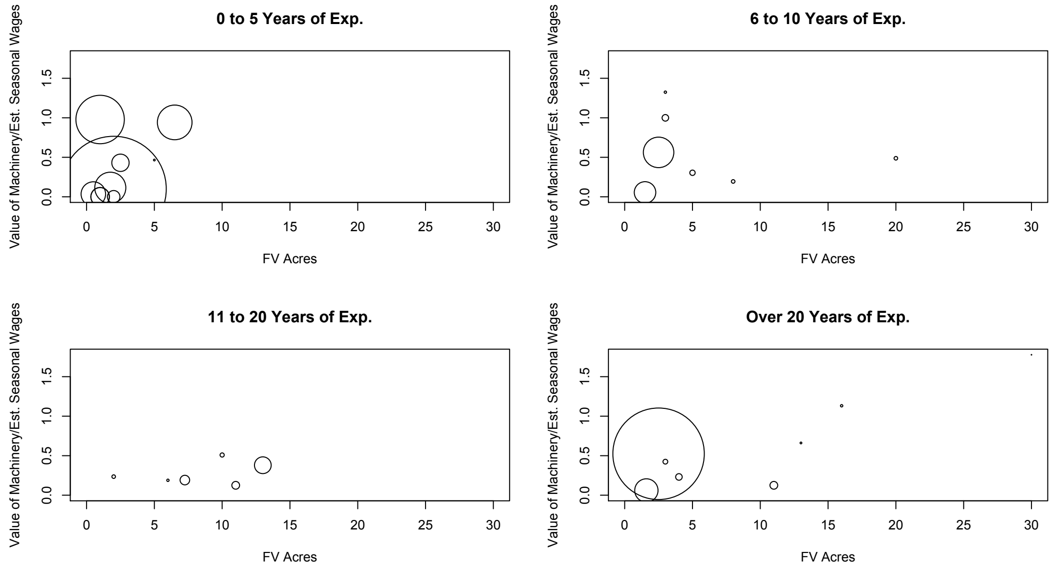

Figure 3.17: Input Ratio, FV Acres, and CPA Divided by Farmer Experience

3.1.3.3 Crop Selection

Stated earlier, the biological constraints of the crops can impact production. Not all of the crops have the same needs. For instance, perennials such as apples or asparagus do not require subsequent planting each year and timing of tasks differ between warm and cool-season crops. This means that separating farms by crops grown is especially important. It may be that a more diverse crop set will be more difficult to mechanize. Similar root crops such as carrots and potatoes can both be harvested with a potato digger for instance.

To start the crop analysis, we will examine the set of farmers by perennials. Farmers were asked to name the primary crops grown on their farm. Farms were categorized by the types of perennial crops grown. For instance if a tree or bush perennial was grown on the farm, it was placed into the “tree perennial” category. If farm grew both tree and another type of perennial, it was placed into the “multiple perennial types” category (Figure 3.18). Several data points had to be dropped because the respondent stated the number of crops they grew without specifying them. Farms growing perennials generally had higher acreage fragmentation and were more likely to be in the second, input intensive group from figure 3.13. However, many farms across these perennial categories mixed quite well to make up the more efficient grouping of farms. Because the heterogeneity of the crops is likely to reduce cross-crop suitability of machinery, multiple perennial crop type producers were expected to use more labor for the size of the farm but it appears that this is not the case. Growers of non-tree perennials made up most of the bottom of the half of the empirical isoquant. Because we do not have the actual acreage of these crops and most farms reported growing other non-perennial crops, it is difficult to assess the actual impact that perennial crops have on inputs.

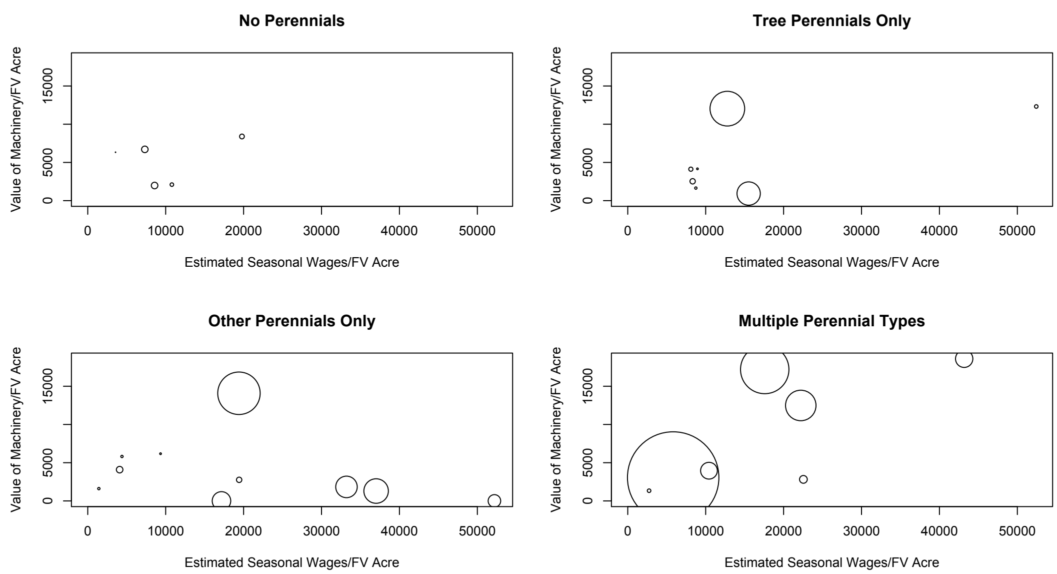

Figure 3.18: Normalized Isoquant and CPA Divided by Perennial Crops Grown

We will now move on to warm versus cool season crops. No farm in the survey grew exclusively cool season crops plotting these farms is useful in two ways. As before, farms growing different crops will be expected to use more labor since the cross-crop machine compatibility may be lower as crops become more dissimilar. Second, exclusively growing one type of seasonal crop may constrain a farmer's time over a particular time period. This may make machines a more necessary time saving tool. This may make farms only growing warm crops more efficient than those that grow both warm and cool season crops.

The seasonal crop plots for the most part seem to support this hypothesis (Figure 3.19). Farmers that grow both warm and cool season crops were expected to use more labor and its plot is much more spread out and accounts for much of the relationship in the input intensive group. Like the perennial crop plots, the seasonal crop plots are quite cluttered. Two of the warm crops fit into the second, input intensive, group. This could be due to the fact that we do not know the relative acreage of each crop. However, as we would expect, farmers growing only warm crops and those that grew neither warm nor cool crops seem to be using inputs more efficiently suggesting that these are better able to mechanize production.

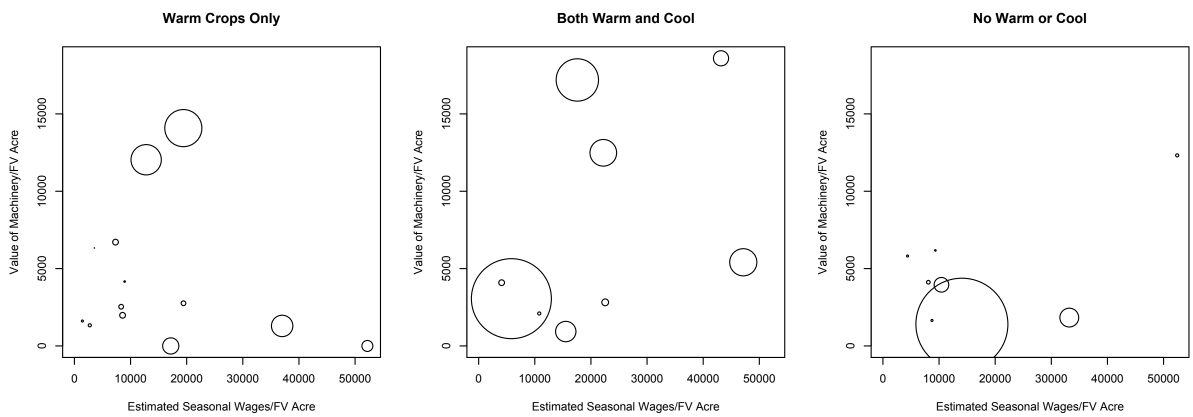

Figure 3.19: Input Ratio, FV Acres, and CPA Divided by Seasonal Crops Grown

3.1.3.4 Regression Analysis

We will now analyze the survey data with a regression to more rigorously test for Cobb-Douglas technology. Using statistical methods on a data set that is small and heterogeneous should be viewed with caution. The usable dataset for this analysis is made up of 30 data points. Under the strict statistical guidelines, this should be enough data to run a simple regressions, the scatterplots suggest that there is a high degree of heterogeneity and may not be identically distributed. Recall again that since the inputs are divided by the acreage, we can assume that production is normalized to one acre. We see that in its most basic form, the production function explains about half of the variation in production. Labor does not appear to be statistically significant in production (Table 3.7). This may be due to the differences between the two groups of producers or from the fact that growers with less than five acres used many different input combinations.

To account for some of the heterogeneity between the two groups, control variables were added in the other two iterations of the model. The idea is that the total factor productivity term in the Cobb-Douglas production function (A), quantified as the intercept term in the model, may not be represented accurately because it is correlated with other farm characteristics that are missing from the model. To account for the effect of economies of scale, crops per acre were added in the second and third iterations. Dummies for seasonal crops were also added to account for the diversity of the crop set. Model #2 and #3 produced similar results. Both lowered the estimated elasticity of output with respect to machinery and the total factor productivity term. All models passed the F-test at 1% significance level.

Table 3.7: Cobb-Douglas Regression Results with a Dependent Variable of ln(Q)

	Estimated Value		
Variable	Model #1	Model #2	Model #3
Intercept	-5.9781***	-4.8907 *	-4.8331*
$ln(L)$	0.2402	0.1924	0.1962
$ln(K)$	0.4912***	0.4471 **	0.4447**
Crops per Acre		-0.0463	-0.0390
Warm Crop			-0.0286
Both Warm and Cool			-0.2829
Adjusted R^2	0.5107	0.5271	0.5053
Sig. Codes :	0.001(***)	0.01(**)	0.05 (*)

We can vet the three models by plotting their estimated normalized production functions with the average input scatterplot (Figure 3.20). It appears that the total factor productivity term was underestimated in the Model #1. Model #1 seems to exhibit the technology of the second, more input intensive group. By accounting for acreage fragmentation, the model becomes much more representative of the survey as a whole. The estimated isoquants in Model #2 and #3 lie near the middle of the two groups of farmers. Adding seasonal crop dummies does not impact the isoquant by much but does bow the isoquant closer to the less input intensive group.

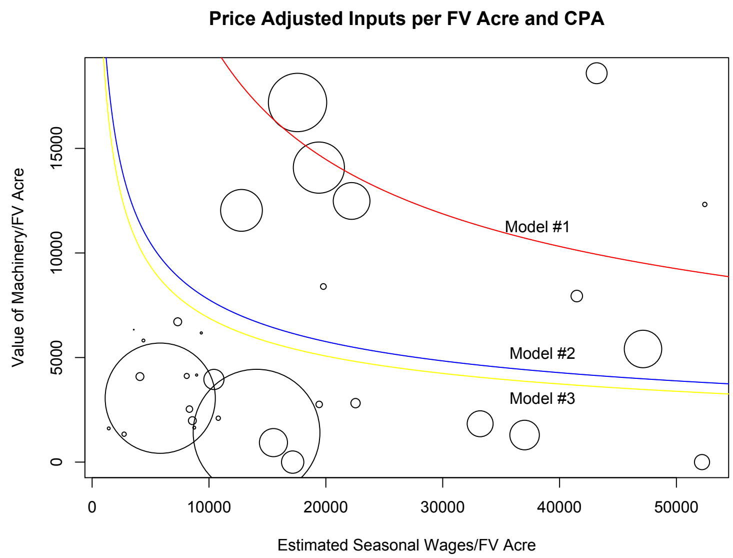

Figure 3.20: Normalized Isoquant Model Comparisons

3.1.3.5 Survey Conclusions

Farms in the survey were highly heterogeneous. Farms came in many sizes, types, and had a variety of crop mixes. This and the grouping of the empirical isoquant emphasizes the complications when using population-level statistics to analyze the FV community. Farmers with more crops per acre tended to grow on less than five acres with various levels of mechanization. Farmers with less fragmented acreage varied more by size and tended to trade labor and machines more distinctly. Crop mix also impacted the inputs. Farmers growing more similar crops tended to be less input intensive than those growing a more varied crop mix. This could be because farmers with more cohesive acreage are better able to exploit machinery economies of scale. While these are important findings, the survey does not capture much detail. We can not provide explanations for these trends with much confidence using these quantitative methods. Further qualitative analysis is necessary. The next section details the findings of a case study. This study provides more concrete answers for how and why FV farmers make decisions. The next section will start by providing descriptions of each of the six farms in the study and then make cross-farm comparisons.

3.2 Case Study Findings

3.2.1 Farm #1: Rinehart's Family Farm

3.2.1.1 Background

Primary Crops:	Sweet Corn, Green Beans, Watermelons, Asparagus, Tomatoes
Primary Marketing Outlets:	Farmer's Market, Restaurant, Farm Stand, Grocery Store, Processor
Total Fruit and Vegetable Acres:	50 Acres
Years of Experience:	20+ Years

Rinehart's Family Farm is located in Boone, Iowa and operated by Greg and Polly Rinehart. Compared to most fruit and vegetable farms in the Midwest, the Rinehart's Family Farm is quite large with 50 acres in fruit and vegetable production. In addition to fruits and vegetables, the Rineharts also grow corn and soybeans on 750 acres. The Rineharts entered into fruit and vegetable production in the late 1980s to serve as an alternative to adverse markets in corn, soybeans, and livestock, which resulted from the farm credit crisis. In the years that followed, the Rineharts increased vegetable production partly as a way to bring their family of 10 kids together in a common and constructive goal.

"There are some years when its hard and we don't make that much but a family that works together and suffers together and prospers together just helps them. And it's been good for all of our kids."

The primary crops grown on the farm in rough order of importance are sweet corn, green beans, watermelons, and asparagus. In addition to these primary crops, they also grow a variety of other crops including cabbage, lettuce, broccoli, peas, and sugar snaps early in the season and tomatoes, peppers, cucumbers, herbs, and onions during warmer months. To increase the variety offered at his farmers' market booths, while not growing a crop set that becomes overly diverse, Greg shares crops with other farmers. Greg is a proponent of using high tunnels to extend the seasons of high value crops like tomatoes. He currently uses two high tunnels on his farm. Greg was instrumental in establishing farmers' markets around the state through inaugural work with the Iowa Farmers' Market Association and the Boone Farmers' Market.

"Now I have a friend that likes to grow strawberries so I let him grow them and I buy strawberries from him and take them to the market. So that helps. I've grown a lot of sweet corn and green beans for other growers too and trade... It's a lot easier if you just grow two or three crops... there are certain knacks. Strawberries are an intense crop to grow. You have to really be on your toes you have to be careful about late spring freezes."

3.2.1.2 Expansion Experience

Before beginning commercial vegetable production, the Rineharts grew corn and soybeans, raised 70 cows and around 1,000 hogs a year. During their first year of vegetable production the Rineharts produced sweet corn to sell at their farm stand for RAGBRAI, an annual cross-state bicycle ride. After seeing the demand for locally grown vegetables, Greg helped establish the Boone Farmers' Market. In the years that followed, the Rineharts began introducing new crops and marketing to other farmers' markets including ones in Ames and Webster City. To ease the transition into commercial vegetable production, they chose initial vegetable crops that were similar in terms of machinery needs to their established row crops, sweet corn and green beans.

"Well being as we grow field corn it was easy to transition into sweet corn and it was easy to transition into green beans... So I just saw that you can use a lot of our same equipment to plant a lot of this stuff. You can even plant pumpkins with our planters if you wanted."

Over the years the farm's fruit and vegetable acreage has varied between 50 and 80 acres but is currently around 50 acres. Although he acknowledges that crop selection is in part determined by preference, crops ultimately must be marketable. By talking with growers at the farmers' markets and attending seminars, Greg began to expand the crops that the farm raises by experimenting with recommended crops that he thought would work for his operation.

3.2.1.3 Labor and Machine Use and Considerations

Family members supply most of the labor on the farm. They hire eight people during an average week in the growing season: two workers to take produce to the farmers' markets and six workers in the field. Many of these non-family workers are local kids between junior high school and college aged who work part-time when they are out of school. More labor is hired during the early part of the season when they are planting and transplanting their cool season crops. This period is especially busy since there are typically fewer workable field days in the earlier weeks because it is usually a wetter time of the year.

Machinery Used	
Power Unit	Implement
70 hp. Tractor	PTO Driven Tiller
50 hp. Tractor	Plastic Mulch Layer
30 hp. Tractor	Transplanter with Water Wheel
Walk Behind Tiller	6 Row Sweet Corn Planter
Walk-In Cooler	12 Row Sweet Corn Planter
	6 Row Small Seed Seeder
	Vegetable Specific Cultivation Equipment
	Corn and Soybean Cultivation Equipment

The Rineharts' fruit and vegetable operation is relatively mechanized. They have benefited from growing field corn and soybeans since the planting and cultivating equipment that is used for field corn is also useful for sweet corn and green beans. In fact, since the processes are so similar, Greg brought up the point that field corn is the primary alternative to growing sweet corn for processing as opposed to other vegetable crops. Even though he extensively uses high tunnels, he notes that his smaller tractors and rototillers can be used inside of high tunnels meaning that in some cases, tractors can complement high tunnel use. When the Rineharts purchase machines their main considerations are cost, labor and time savings. To the Rineharts, labor and machinery are substitutes, especially at higher levels of acreage.

"You do what you need to do to make either cost savings or labor savings. So the first thing you get is some kind of tractors if you are going to get bigger. Then your next thing is probably your tiller. And the next thing you need to buy is some kind of planter, a combination of planters... Most of these labor saving devices are so that you can get it in earlier and quicker... you don't need all of this [equipment] to get started. You need some land and just start growing and you substitute. Either it takes a lot more people or substitute with equipment or find the right balance. Every operation needs to do that. If we had a lot of people but you still have to pay them a lot of money well then that won't be profitable. "

3.2.2 Farm #2: Patchwork Green Farm

3.2.2.1 Background

Patchwork Green Farm is located in Decorah, Iowa and operated by Erik Sessions. The entire farm is comprised of 41 acres but Erik grows fruits and vegetables on five of them. Due

Primary Crops:	Squash, Potatoes, Garlic, Onions, Lettuce, Cherry Tomatoes, Carrots
Primary Marketing Outlets:	Farmers' Market, CSA , Cooperative, Restaurant
Total Fruit and Vegetable Acres:	5 Acres
Years of Experience:	15 Years

to the topography of the property, not all of these acres can be used for fruit and vegetable production; 25 acres are enrolled in the Conservation Reserve Program (CRP) and the remaining acreage not in production is timber. Typically around another half acre is used to produce a perennial cover crop. The farm has three high tunnels to help extend the season on cherry tomatoes, to cure garlic and onions, and to serve as a propagation area. Aside from the fruit and vegetable enterprise and CRP income, there are no other sources of on-farm income.

To provide a stable and diverse supply to CSA members and the Decorah Farmers' Market, multiple plantings of a variety of crops are planned throughout the season. Harvesting their half acre of garlic and the onion and potato harvests are the busiest times of the season. Unlike most of the other crops that are harvested throughout the season, the garlic harvest takes place at one time. Every year Erik experiments with these crops to find better mixes of marketable and manageable crops to grow. Like Greg, some of these crops are harder to manage for Erik because they differ in some way from the other crops that he grows.

"There's demand for sweet potatoes at the farmers market. I've tried them a couple of times and I've had really poor luck. Part of it is not keeping on top of the management. It's a little different than growing other crops. I just wasn't keeping up with it really well."

Erik is also experimenting with his marketing. In addition to a providing traditional CSA shares, he provides a CSA market share. Like a traditional CSA, market shareholders pay a flat fee at the beginning of the growing season. However, instead of receiving a bag of produce that the farmer prepares, market shareholders open a prepaid account that is used at the farmers' market. This allows market shareholders to pick what kinds of vegetables they receive and to purchase them at their leisure. Approximately three quarters of the output goes toward the CSA and the farmers' market.

3.2.2.2 Expansion Experience

Erik's initial production took place on two acres of rented land in 1998. Before starting farming on his own, Erik apprenticed at a 5 acre CSA for a summer in the mid 1990s. This apprenticeship showed him that a farm can economically operate on five acres and inspired him start a local fruit and vegetable farm of his own. The farm that he apprenticed with served as the initial template of his own farm.

> *"Having grown up in Iowa where if you don't have a couple hundred acres of corn you're not making it. I thought 'oh five acres that sounds reasonable.'... The first four or five years in particular of doing our own stuff here both on rented land and when we moved over here, we very much basically started with their model."*

For the first three years, Erik continued to rent the two acres and grow for Decorah's farmers' market until he purchased five tillable acres of his own in 2001. Though his crop mix remained roughly unchanged throughout this acreage expansion, the fact that the expansion traded rented for owned acreage meant that improvements to the property became prudent. He installed a deer fence as the owned property was surrounded by timber. He also installed a pump system and drilled a water well to facilitate drip irrigation and a washing area.

3.2.2.3 Labor and Machine Use and Considerations

During the first three years when production took place on the two acres of rented land Erik did not hire any workers. After the transition to the owned property, Erik hired a local high school student to work about 10 hours a week over a few weeks in the summer. For about four years, this was the extent of the farm's hired labor until the birth of Erik's second child in the middle of the summer. Having to take care of a newborn while maintaining the CSA and farmers' market production was simply too much work so he hired an employee to work 20 hours a week for the rest of the season. The following year, he continued to hire an employee for 30 hours a week. Over the past four seasons Erik has hired an additional laborer where one works about full-time and the other works half time. Erik's kids are young and his wife has a full-time job in Decorah so with the exception of his wife's help during garlic harvest most of the labor comes from himself and his employees. He cites that the level of crop diversification as the primary reason for adding on another employee.

"Working the amount of ground we have and the variety of crops, harvesting isn't just go[ing] out and pull[ing] onions. You're harvesting 25 different things in the whole summer, it's hard for one person trying to get all of that stuff done."

Machines Used	
Power Unit	Implement
30 hp. 4WD Tractor	Bush Hog Mower
8 hp. Walk Behind Rototiller	5 ft. Rototiller
Walk-In Cooler	Tandem Disk
	Broadcast Seeder
	1 Row Potato Digger

Erik has made many changes to his machine fleet since he began farming. Over the first three years he used only hand tools and a walk-behind tiller while he was farming the two rented acres. Most of his initial machinery purchases were second hand. His first major purchases were a Ford 9N tractor, a brush mower and a disk. These purchases were made so he could better manage the soil nutrient content. A walk-behind tiller cannot incorporate a cover crop very easily. Other early purchases include a used horse-drawn potato digger that had been retrofitted for a tractor and several small second hand glass top freezers from a grocery store.

Throughout the last eight years, Erik has been updating his machine fleet with purchases of new equipment. These updates included a walk-in cooler to replace the smaller units, a new 30 horsepower four wheel drive Kubota tractor to replace the old 9N, a three point hitch tractor-drawn rototiller, a tractor-mounted broadcast seeder for cover crops, and a new one-row potato digger. Many of these purchases were made because the equipment was outdated and had too much downtime in the field. When purchasing a piece of equipment he considers how often he would use the machine throughout the year and whether there are cheaper alternatives such as custom hiring for spreading fertilizer. Extending the season was also important as he added two more high tunnels since production shifted to the five owned acres. The walk-in cooler and water well are especially important to Erik.

"Having done it now for a couple of years we knew better what questions to ask other producers so another guy that had a vegetable operation nearby I think his line was 'don't even bother doing veggies unless you've got a way to cool your produce and irrigation. Those are just necessities. When you're first starting out you thinking ok I need a tractor, I need to till the soil, I need seeds, I need a market to sell it at. But you've got to make sure you've got irrigation so you can grow quality crops, you've got to have a way to get them full chilled down to 33 degrees so when you take that lettuce in at [an] August market"

3.2.3 Farm #3: The Schlife Farm

3.2.3.1 Background

Primary Crops:	Asparagus
Primary Marketing Outlets:	Grocery Stores, Restaurants, Farmers' Market Indirectly
Total Fruit and Vegetable Acres:	4 Acres
Years of Experience:	8 Years

The Schlife Farm is located in Polk City, Iowa and is owned by Tom Schlife and Mary Ann deVries. This farm is unique in that it grows only asparagus on four acres of land. In addition to commercial production of asparagus, Tom currently grows corn and beans on an additional 40 acres. There are about 150 apple and asian pear trees on the property but these are used to feed their rescue horses and casual U-pickers. Unlike most of the other growers that were interviewed, the bulk of the on-farm income comes from one vegetable crop. They chose to grow only asparagus because of its short growing season and, since it is a perennial, it does not require planting each year.

"We just do asparagus because it's a 30 day crop and then we're done. None of this all season long farmers market stuff... Man we only have to do this for month. I can handle a month even though there's a lot of pressure. A month and its done."

Most of the output is marketed through grocery stores and a hand full of local restaurants. Most of these outlets request asparagus periodically throughout the growing season and sometimes vary on the amount that they request each week. Any of the excess production over these weekly orders is sold to another grower that has a booth at the Des Moines Farmers' Market. This excess production could be as large as 500 pounds of asparagus. One of the reasons why he stays directly out of farmers' markets is that he only grows one crop and can not maintain a supply of the crop over the entire market season.

"Last year it we were doing it by the middle of April, we started picking, by the middle of May we were done last year. We had done our 30 days, no matter what the weather is you only harvest for one month that's it. We were done before the first market, basically we were almost done before the first market even started."

3.2.3.2 Expansion Experience

Schlife's asparagus production started modestly with two gardens that were originally planted as a way to grow asparagus to give away to friends. While producing in the gardens, Tom and Mary Anne learned how to produce high quality asparagus efficiently. Asparagus is a unique crop in several ways. It is a perennial crop meaning that sequential plantings are not needed in order to produce a crop each year. Another important characteristic is that it produces continually for about a month each year and requires a strict daily harvest regimen to prevent waste. After producing in the gardens for several seasons they realized that commercial production was feasible, then expanded to four acres.

"...it just got started and then 'Wait a minute, we kind of know more about this than a lot of people why don't we just try it?' And roots out of New Jersey were really cheap."

The transition into these acres was fairly quick and effortless, no stoop labor was needed to plant. Since asparagus is typically planted 10 inches below surface of the soil, it takes about a year for it to produce after planting. During the second season after the expansion, Tom allowed a close friend's son and his friends keep the profits from the first crop if they harvested and marketed it themselves. This arrangement allowed Tom to learn about production and marketing considerations under the new acreage without directly investing time and effort. No expansions are currently planned. Tom has considered expanding in the past but cites labor requirements and asparagus demand as constraints.

3.2.3.3 Labor and Machine Use and Considerations

Labor is an important input on the Schlife Farm. Harvests must be conducted over the entire acreage without fail every day of the growing month, sometimes multiple times when it gets hot. As far as hired labor, Tom has hired the same worker for the last six seasons. For most days, this one worker can harvest the entire four acres every day. On warmer days the asparagus grows faster meaning that Tom and, at times, Mary Anne will have to go out and help as well. In the evening when all of the asparagus is harvested, it is snapped, washed, and bundled by Tom and Mary Ann. Being able to see how the boys faired in the first season was a helpful gauge of how much labor was needed to maintain a steady harvest throughout the month of production.

"We kind of knew how much work because we saw those guys. And they had to keep up with it and they didn't do this very good but still. When I started seeing that it wasn't being harvested through the week, and they were just doing it for two or three weekends but they harvested it through the weeks. If they weren't keeping up they got in trouble they had to get back out there."

Machines Used	
Power Unit	Implement
Lawn Tractor 2 ft. by 48 ft. Foot Refrigeration Trailers	Spring Tooth 4 Row Sprayer 6 Row Lister

Machines are not used much for the Schlife farm's asparagus and are mainly devoted to cultural tasks. These are tasks that are associated with maintaining the soil and crop between harvests. Tom experimented with harvesting equipment after the expansion. Although there are not many generally accepted asparagus harvesting aids, he purchased a harvesting assistant, an implement on which workers lie face down on low hanging platforms to avoid stooping during the harvest. For several reasons, this implement was sold after only two seasons. Firstly, the harvesting assistant required two pickers and a tractor driver to operate, meaning that their labor use would actually rise. The variable rate of asparagus growth also made it difficult to effectively match the work speed of the two pickers.

"I had a machine where they would pull it through the field where those guys lay down, these would have been 9th graders. I can remember hearing them out there yelling at each other 'you're going too fast, too slow, don't hit that rock [dink, dink, dink].' It didn't even work for young kids at that time. It didn't work out really good."

Primary Crops:	Beets, Tomatoes, Peppers, Cucumbers, Summer Squash
Primary Marketing Outlets:	Farm Stand, Farmers' Markets, Co-op
Total Fruit and Vegetable Acres:	5 Acres
Years of Experience:	15 Years

3.2.4 Farm #4: KyMar Acres

3.2.4.1 Background

KyMar Acres is located in Waukon, Iowa is owned by Kyle and Mari Holthaus and operated by a close knit family group including Mari's sister Anna Herzmann. KyMar Acres works closely with the farm of Mari's parents, Lee and Kathy Newman in Mabel, Minnesota approximately 40 miles north of KyMar Acres. These farms often make joint decisions including purchasing and sharing machinery and sharing crops at either location. One of the benefits of this arrangement is that it diversifies the risk of adverse weather and allows for a degree of crop specialization.

"If they need anything to fill in for farmers market, if we have it in season down here. Part of the reason we started doing that, having the two places was, this year was a good example. They got every rain that we missed out on. We'd be down here trying to break in the ground and you'd go up there and you'd be kneeling in mud. So having that, it's a 40 mile difference in distance so it works out well that way."

Their primary crops include beets, tomatoes, peppers, cucumbers, and summer squash however they also grow an assortment of herbs, onions, and a variety of cold crops with the exception of spinach and other greens. Besides their fruit and vegetable acres, they generate on-farm income from three acres of hay and from livestock including a flock of ten sheep and 100 laying hens. They market in several ways throughout the season. Early in the season when the scale of production is not appropriate for cooperatives and farmers' markets are not yet open, they operate a small farm stand. Aside from this short period, production is mainly marketed through the GROWN Locally co-op and through farmers' markets in Decorah and Waukon.

"on-farm sales in the spring for starting plants and what vegetables are ready at that point...once that season is kind of done, we close that on-farm stand just for the fact that the production really kicks in and there's mainly two of us that do most of it...the farm stand is just a drop in the bucket compared to everything else...normally its about 80-20 wholesale [Co-ops] versus farmers market."

Expansion Experience When they first bought the farm, Kyle and Mari had 7 acres of tillable ground in 1998. They started off producing corn and soybeans but found out it wasn't economical. The next season they started a garden, built a 12 by 24 foot greenhouse, and connected themselves with the GROWN Locally co-op. At this level of production, they performed all their tasks by hand and with a walk-behind tiller. The season after they started their gardens, they increased production to one acre. They purchased a small garden tractor and a tiller to make transition from garden level to field production. In their third season, they purchased a 35 horsepower Agco tractor and a larger tiller. After the purchase of the Agco tractor, the farm expanded approximately a half-acre each year until 2008. One reason for the expansions was to have a better way to handle crop spacing issues.

"Then when we started getting the bigger tractor and tiller we started obviously tearing more up and trying to figure out better ways of laying it out so it wasn't quite so crowded and we had a little bit more space to use."

KyMar Acres has gone through an expansion and is currently undergoing an expansion into tree crops and adding a certified commercial kitchen. Both the kitchen and the expansion into fruit trees are planned so that value-added products like pies, canned fruit, and jams can be offered at farmers' markets on a larger scale. In addition to using their kitchen themselves, they also plan on renting it out to generate a source of guaranteed income.

3.2.4.2 Labor and Machine Use and Considerations

Machines Used	
Power Unit	Implement
35 hp. Tractor	Tiller
45 hp. Tractor	Disk
Four Wheeler	Cultivator
Walk-In Cooler	Ecoweeder
	Potato Digger
	Transplanter
	Mulch Layer
	Mower
	Four Wheeler Harvest Trailer
	Jang 3-Row Planter with 9 Plates
	Jang 1-Row Planter with 9 Plates
	Earthway Seeder

KyMar Acres is unique with respect to both their labor and machinery usage. For the most part, farm jobs are highly specialized between Kyle, Mari, and Anna. Aside from some help from Lee and Kathy, these three provide most of the labor for the farm. Kyle works in the parts department for the Decorah branch of the Case IH dealership, Windridge Implements, and Mari works as a tax preparer during the tax season but both are highly active in the farm during off-work hours. Kyle primarily handles the weeding, harvesting, and the preparation to get the vegetables market ready. Mari plans out the planting and seeding schedules, the planting and greenhouse work, and harvests as well. In addition to her on-farm duties Mari is the sitting president of GROWN Locally co-op and is active in the WW Kellogg Foundation, an organization that advocates for healthy eating and activity. Anna primarily handles the marketing side of the fruit and vegetable enterprise. This includes creating advertisements, working in sales, and washing and packing vegetables for market. Anna also assists Mari during the tax season with secretarial duties and supplements her greenhouse duties during the busier times. Working hours tend to vary over the season due to obligations from off-farm work and the needs of the farm. The Holthaus and the Herzmanns each have two younger kids, each around 12 and 9 that also help with task around the farm.

"So it is a pretty good family affair then. We all fill in and pitch in... We try to find out our own strengths."

Through Kyle's ties with Windridge Implements, KyMar Acres borrows small-scale fruit and vegetable machinery from Windridge. This borrowing arrangement began when Windridge Implements began selling small scale fruit and vegetable equipment five years ago. Kyle borrows most of the farm's equipment that is specific to fruits and vegetables like their transplanter, mulch layer, ecoweeder, potato digger, and Jang 3-row seeder. In exchange for the privilege of borrowing machines from the dealership, KyMar Acres hosts an annual field day for the dealership. This field day allows prospective Windridge customers to see fruit and vegetable equipment works in the field.

Since many of the implements on the farm do not have to be purchased, it is challenging to get a sense of what the machinery is actually worth to the farm. However, since they have so many implements they are able to offer perspective on nearly all of the machine options that a small fruit vegetable farmer has at an equipment dealership. The borrowing arrangement between the Windridge and KyMar Acres has worked out well for the farm. Since they started borrowing from the dealership, the farm has not expanded but production has increased and fewer hours are required to work their 5 acres. Equipment efficiency, versatility and the availability of alternatives are important factors when Kyle considers equipment.

"We've discussed the fact that if we had to buy one piece of equipment, it would be the ecoweeder. That is the hands down the one thing that we would buy... It would be by far, that is by far the most time saver. The next one as far as importance to our farm would be the potato planter because we use that for the potatoes, the gladiolas, the tulips, and the garlic. Then after that... the one row transplanter. Because we have other ways of cultivating and tilling the potatoes, and stuff. Then depending on how well the potatoes do and how much we actually plant depends on if we want to borrow a harvester [digger]...The mulch layer though is pretty handy...we put that [on top of] almost all of the peppers and the tomatoes."

Not all of the machines on the farm are borrowed. The tractors and cultivation tools purchased to be community property between KyMar Acres and the farm in Mabel, Minnesota. Until a year ago, the farms had to share one tractor between the two farms. Since the tractor was used so often and had to move so far, they purchased a Farmall 45 tractor to keep at the Mabel farm. Now sharing machinery is much easier since, the two farms mostly share implements that are small enough to be transported with a pickup truck.

"...the Agco started out as a community tractor and then the 2nd tractor is still a community tractor [the Farmall 45]. One stays one place and one stays the other... Before that, we would basically have it a week down here and we'd take it a week up there."

3.2.5 Farm #5

3.2.5.1 Background

Primary Crops:	Sweet Corn, Watermelon, Cantaloupe, Pumpkins
Primary Marketing Outlets:	CSA, Grocery Store, Farmers' Market, Farm Stand
Total Fruit and Vegetable Acres:	21.5 Acres
Years of Experience:	11 Years

The owner of Farm #5 wished to remain anonymous. The farm is comprised of 21.5 tillable acres divided between an acre and a half section on the homestead property, a 5 acre section across the road and a 15 acre section, both within a 10 minute walk of the homestead. Aside from vegetable production, there are no other activities on Farm #5. The primary crop grown on Farm #5 is sweet corn, which takes up 10 acres of tillable ground. Other prominent crops that Farm #5 grows are watermelons, cantaloupe, and pumpkins as well as a variety of other crops. In rough order of gross sales Farm #5 markets these crops through a farm stand, several grocery stores, wholesale to Iowa State University, a farmers' market, and a 40 person CSA. Saving on the labor that it takes to market is important to Farmer #5. To ensure that field work does not have to stop and to avoid having to pay an extra person, the farm stand sales rely on the honor system and the grocery store and CSA customers have to pick up their produce at the homestead. The clientele between Farmer #5's marketing outlets can be unique. In addition to order sizes, Farmer #5 also notices that certain crops like carrots sell for CSA members may not sell at the farmers' market. One of the major challenges in terms of marketing is the tradeoff between the premium of direct selling through the farm stand, CSA, and farmers' market versus the more guaranteed income from wholesale production to grocery stores.

"...[grocery sales are] not a contract it's a relationship between the produce manager and me...they want to sell it for $2.77 a dozen and my wholesale price to them is $3.50. I can't really sell it, even at cost their cost... I've got inputs, fertilizer and chemicals to keep weeds down... I've thought about... talking to corporate and putting in so many acres of sweet corn. It would be the more the guaranteed sales but... I'm not there yet...Farmers' market, if the moon in the sky is wrong and if for some reason nobody wants to buy green beans... Farmers' market is 'guess and by golly' on what you're going to take and what's going to sell."

3.2.5.2 Expansion Experience

Before Farmer #5 started farming, Farmer #5 lived on the acre and a half homestead and worked full-time off-farm job. During this time Farmer #5 rented the property to another experienced fruit and vegetable farmer. While renting the property out, Farmer #5 developed a friendship with the renter and learned how to grow fruits and vegetables on his model of production by helping him. Over those eight years, Farmer #5 learned how to grow fruit and vegetable crops with the renter's model of production.

"...he basically got to the point where he'd come plant on the property around me and he'd never come back. I would harvest all the tomatoes for him, I would weed it, I'd take care of it...I would go to farmers markets with him so I was learning lots. He wasn't really paying me anything..."

After eight seasons of helping the renter on the homestead property, Farmer #5 decided to start farming independently. For several seasons of growing on the homestead property, Farmer #5 decided to expand to increase production and become more competitive at farmers' markets. Sweet corn, cantaloupe, and watermelon production especially increased after these productions.

"...we would be there with our one little table and our little tiny canopy and they'd be over there with their five tables and three canopies and it just wasn't working. We needed to grow and get bigger."

Over the life of the farm, Farmer #5 obtained acreage from several sources. When the farm was first started, it was hard to find rented land to expand on. The farm's first two expansions were on rented acreage seven miles away from the homestead. This distance meant that it took a lot of time and fuel to transport machinery to prepare and harvest crops. After six years in production, neighbors closer to the homestead became more open to selling land to Farmer #5 and enabling Farmer #5 to add 20 acres within a 10 minute walk from the farm house.

"I'd been begging to find land around but in 2008, I was offered up 40 acres if I wanted it. I think partially the reason was that people realized that I'm not just a fly by night deal and I'm big enough... I got the 5 acres and the 15 acres plus the acre and a half at my house."

3.2.5.3 Labor and Machinery Considerations

Machines Used	
Power Unit	Implement
25 hp. Tractor	5 ft. Tiller Middle Buster Cultivator 6 ft. Brush Cutter Airblast Plastic Mulch Layer Transplanter with Water Wheel 6 ft. Disk

Machine use has changed a lot since production began. The first two years were challenging since Farmer #5 had to perform most of the farm's tasks by hand. Unlike the other farmers in the case study, Farmer #5 does not use any commercial refrigeration besides air conditioning to keep produce cool. To help with the transition the former renter came out with a tiller and a plastic layer to help start the farm's production. Because there was a source of off-farm income, most of the profits from the farm went into machinery investment. Initially, the biggest machinery concern was tilling equipment. The first major purchases were a 25 horsepower 8N Ford tractor, a six-foot disk, and a brush mower**.** Although they were a step in the right direction, these initial machine purchases were not very efficiency since it took several passes to get the soil ready for planting. Later on Farmer #5 sold the 8N tractor and purchased a 25 hp John Deere 850 tractor and a five foot tiller followed by a water wheel transplanter and a plastic layer in the following year. Farmer #5 made these purchases for three primary reasons. First, Farm #5 was beginning its first expansion and tasks still needed to be completed in a timely manner. Second, the last few seasons had been profitable enough to begin major investments in the machine fleet. Third and most importantly, from the experience working with the former renter, Farmer #5 knew how to work with these machines and how more easily and effective they were before purchasing them.

Though Farmer #5 does not plan on expanding acreage in the near future, he hopes to purchase equipment. However, since Farmer #5 acquired the 15-acre section there has not enough money for these machine purchases. A larger tractor and cultivation equipment would be especially useful for managing larger sweet corn fields. An additional tractor would also complement the current machine fleet since Farmer #5 would not have to spend time switching implements on one tractor.

"What I really need is a 70 horse [tractor] with a 20-foot disc cultivator... That 15 acres, my little 25 horse tractor with a five foot tiller, it gets a workout for it and it's a time consuming. So when I go out to plant, I used to disc my sweet corn but it's an uneven ground, it doesn't make a nice level bed... It takes me about three hours to till an acre and that's in 3rd gear going pretty fast, pushing the tractor, overheating... And just having one tractor with the cultivator on it and the other tractor with the airblast on it and not have to switch out constantly... I just get sick and tired of taking equipment off and putting equipment on..."

Unlike machinery, changes to labor have not been as frequent. For the first six seasons, Farmer #5 performed all of the farm's tasks while working full-time at his off farm job. After purchasing the acreage across the road from the farm and comparing his wages on farm profits, Farmer #5 quit his off-farm job. Besides transitioning to farming full-time the only major change to labor usage on the farm was hiring a high-school part-time worker for the last two seasons. In addition to hired labor, Farmer #5 also has a 15 year old son who helps with field work and a father-in-law who hand picks green beans. The justification of the marginal product for the wage is a big consideration for Farmer #5 when he hires labor.

"We have a strawberry patch... we decided a lot of them are going to waste, we are not getting them all picked. So we hired four people to come out and help pick. We told them you'd get $2 a quart and that would be their pay... some of them just wanted to fill the quart and make that two dollars. So they're putting rotten ones in, they're not paying attention. We did the figures... we worked harder to move that product but still made the same money after we paid the help... We have hired this girl the last two years. Has she actually made us money? Probably not.... but it is handy to have some help. But I need to be able to have that person make me money."

3.2.6 Farm #6

3.2.6.1 Background

Primary Crops:	Salad Greens, Cherry Tomatoes, Peppers, Egg Plant, Cucumbers, Garlic
Primary Marketing Outlets:	Co-op, Grocery Stores, Farmers' Market, Restaurants
Total Fruit and Vegetable Acres:	3.5 Acres
Years of Experience:	8 Years

The owners of Farm #6 also wanted to remain anonymous. It is owned and managed by a husband and wife team, both will be called Farmer #6 in this paper. Besides vegetable production, there are no other sources of on-farm income but Farmer #6 is also the part owner of an off-farm agribusiness. Farmer #6 is primarily concerned with cornering the market of high value crops especially during times of the season when supply is typically low. Farmer #6's strategy involves selecting differentiated crops to grow and focusing on season extension. Farm #6 is highly invested in greenhouses and has a total of approximately 6,500 square feet of space and has all organic production. Farmer #6 hopes that by providing a stable supplier in these niche markets they will grow relationships and lead to more opportunities with customers. Most of the output is marketed through a cooperative, which grants access to a large wholesale network that has sustained demand throughout the year.

"For us we were able to find a niche product to be able to jump into... and then just in time you start to see more of those cracks... I would almost rather be in a place where I farmed August through April and be done...the revenue is there."

3.2.6.2 Expansion Experience

Before starting farming, Farmer #6 called produce in a co-op. Farmer #6's first experience in commercial vegetable production was helping to manage a farm for an accomplished fruit and vegetable farmer for two years. This experience was influential in inspiring Farmer #6 to start an organic small acreage fruit and vegetable farm and provided a production and marketing model to do so profitably. After a several of years of farm management and consulting experience Farmer #6 decided to start farming independently. They have been at the same level of acreage for the last four years and just this year decided to rent an additional three acres that has not been put into production yet. Along with this expansion of acreage Farmer #6 is also expanding acreage in late season production by adding an additional 1,500 square foot in high tunnel. Adding these three acres however, does not constitute a proportional increase in the acreage that Farmer #6 grows on in a given season. The decision to nearly double the farm's tillable acreage was in part made to help maintain the soil through rotations.

"The reason that we needed that land has been is because we were growing more garlic and more seed cucurbits, than we had land for... we were going to go from a quarter or half an acre worth of garlic seed production in a year to an acre...we need 5 years between planting locations at a minimum. So we need 5 acres, we got 3 with a portion of it in high tunnels. So we needed that 3 acres and the 2 that are not involved in any sort of high tunnel production here, we get an acre worth of garlic planted on a 5 year rotation."

3.2.6.3 Labor and Machinery Considerations

The previous farm management job and being able to talk with other growers through the off-farm agribusiness helped educate Farmer #6 on the labor and equipment needs for their level of production. Until two years ago, most of the farm's labor came from the husband and wife team. Two years ago they met a college-aged student that offered to work on the farm as a volunteer in order to learn about organic farming. Last year he was hired as a full time worker and divides his time between on-farm duties and the off-farm agribusiness owned by Farmer #6. On average everyone working on the farm works approximately 20 hours a week at Farm #6.

Machines Used	
Power Unit	Implement
Walking Tractor	30 in. Bed Former
Walk in Cooler	Flail Mower
	6 Tooth Cultivator
	Brush Mower
	Blade
	Hiller

Because of the emphasis on greenhouse and high tunnel production and low acreage, Farmer #6 uses a walking tractor instead of a standard tractor. A walking tractor is a larger walk-behind tiller that has a power take off and is able to run smaller implements like a standard tractor. The walking tractor is limited in some ways since it can not operate a bucket lifter or have significant draw power. Since Farm #6 is not very large relative to most row crop operations, they can cheaply hire a neighbor to perform more of the larger and intensive tasks such as incorporating cover crops. Although there would be use for a standard tractor on Farm #6, they are not willing to incur the price the tractor which can be much more expensive.

"... I can pretty well manage 3 acres with that walking tractor. It's a 5th of the cost? Of a standard tractor. Once you start talking about all the implements even less than that maybe a 6th to an 8th of the costs... Again there is going to be more time involved and I'm not mechanically cultivating, I'm not mechanically seeding. But I can still form beds, I can still cut tall grass or cover crops in. You can get a flail mower for it, you can get all of the same tools for that but there's a point at which... I've kind of found for what I've got, the next point for me in growth once we really break into 3 additional acres and we're managing 6 acres, I can justify a tractor with a bed former and mechanized cultivation and things like that."

3.2.7 Compare and Contrasts

3.2.7.1 Farms Sharing Equipment

The analysis begins by comparing farms by the selection criteria that are outlined in the appendix (Tables 3.9, 3.8). This first comparison is between farmers that share and those that do not share equipment. Out of the six case farms, two shared equipment. The original hypothesis is that sharing would reduce the cost of acquiring machinery by dividing the fixed costs and therefore make it easier to acquire. There were similarities between these sharing arrangements since they both were between blood relatives. One of the reoccurring issues that the machine sharing literature brings up is timeliness. Timeliness is a problem associated with machinery sharing when more than one farm wants the shared machine at the same time. This is prevalent in agriculture since weather is volatile and may shorten the time window when both farms need to complete tasks. Both farms cited that timeliness was a consideration in the sharing arrangement and each had their own ways of managing the time schedule.

Farmer #1's arrangement involved a bean picker which is a heavier piece of equipment that is hard to move from farm to farm. To avoid moving the picker, one of the farms would plant the joint green bean acreage so the green bean picker could stay at one location and the cost of

Table 3.8: Explanations for Machinery Choices in Case Study

	Farm #1	Farm #2	Farm #3	Farm #4	Farm #5	Farm #6
Acquisition Justification						
Decreased Costs	Tillage Eq., Tractor	Mulch Layer		Planting Eq., Mulch Layer, Seeders		Riding Tractor, Walking Tractor
Decreased Effort	Tillage Eq., Tractor	Broadcast Seeder, Mulch Layer			2nd Tractor	
Decreased Labor		Tandem Disk		2nd Tractor	Transplanter, 2nd Tractor	
Decreased Work Time		Tillage Eq., Tractor		Ecoweeder	Transplanter, Tillage Eq. 2nd Tractor	
Few HL Alternatives		Tillage Eq., Tractor		Seeders	Tillage Eq., Mulch Layer	
Other Income	Large Tractors, Corn Eq.					
Non-Acquisition Justification						
Lack of Availability						
High Cost		Manure Spreading Eq.			Green Bean Harvester	Riding Tractor
Needed Farm Changes		Potato Digger		2 Row Eq.	Green Bean Harvester	
Insufficient Gains		Manure Spreading Eq.				Mulch Layer, Bucket Loader
Preferences		Potato Digger	Asparagus Harvester	Walking Tractor, Transplanter	8N Ford Tractor	

Table 3.9: Case Farm Criteria Summary

	Farm #1	Farm #2	Farm #3	Farm #4	Farm #5	Farm #6
Related Machinery	–	Potato Digger	–	–	–	–
Custom Hired Machinery	–	Manure Spreading Eq.	–	–	Larger Tillage Eq.	Larger Tilling Eq. Compost Spreader
Shared Machinery	Green Bean Picker	–	–	Tractors, Tillage Eq. Refridgeration Truck	–	–
Primary Cool Crops	–	Potatoes, Onions, Lettuce, Greens	–	Beets	–	Greens, Spinach
Primary Warm Crops	Sweet Corn, Green Beans, Watermelons	Tomaotes	–	Squash, Tomatoes, Peppers, Cucumbers	Sweet Corn, Cantaloupe, Pumpkins, Melons	Tomatoes
Primary Perrenials	Asparagus, Watermelon	Garlic	Asparagus	–	Melons	Spinach
Other Farm Activities	Row Crops	–	Row Crops, 12 Laying Hens	100 Laying Hens, 10 Sheep	–	–
Number of Machines	13	8	5	16	8	8
Number of FV Acres	50	5	4	5	21.5	3.5
Number of Workers	12+	3	2	5	2	3
Expansion Types	Scale, Diversificaiton, Temporal	Scale, Diversificaiton, Temporal	Scale	Scale, Temporal	Scale, Temporal	Scale, Diversificaiton, Temporal

Farmer #1

"It was kind of a heavy piece of equipment... we're only about 12 miles apart. So you want to be fairly close if you're going to share that's important. A lot of it is timeliness, that's why it's hard to share. When they want to plant then you want to plant... you just work it out."

Farmer #4

"It would never fail, when [the tractor] wasn't here, we could have been using it and when it was [here] it was raining."

the green bean picker and the harvested green beans were divided between the two farms. The joint acreage would change from season to season to avoid a single farmer having to bear the costs of operation and opportunity cost of holding the other farm's green bean acreage. Farmer #1 is not currently sharing the picker anymore but still is in possession of it. This arrangement started because at the time green beans were in high demand at the farmers' markets, both farms had substantial acreage in green beans, green bean pickers are a pricy but highly efficient alternative to hand picking. As the demand for green beans started to decline, it was not as economical to grow as many acres of green beans. On Farm #1's current level of production, it does not make sense to employ the green bean picker at all and it remains idle.

Farmer #1

"... we got to the point where we didn't need to make green beans. It took a lot of work. You have to have about eight people to run the green bean line, six to eight to do a good job and that takes a lot of work... We still have it up in the machine shed. We may sell it or we may decide that to get more green bean production if Hyvee wants us to grow more... we kind of transitioned from that. We didn't think we needed as much green beans every week."

Farmer #4's sharing arrangement started as sharing a tractor and implements between his in-laws' farm. These two farms make many joint decisions outside of machinery including sharing production and make joint projects such as building greenhouses. As soon as there was enough money between the two of them, they collectively invested in another tractor, the two farms purchased another "community" that could be located at the other farm on a more permanent basis. The second tractor made it easier to share equipment between the two farms since they no longer needed to transport larger, multipurpose equipment.

Farmer #4 also shares equipment through GROWN Locally, the co-op the farm associates with. The co-op has been a good outlet for Farm #4 since it creates standards for the growers that it markets for and is able to market to larger customers by pooling orders together. The

Farmer #4

"... that made a hell of a difference this last year. We just drop the tiller in the back of the truck and away they go. We share the implements back and forth. And that's a lot easier."

co-op also helps with the physical delivery to these larger customers by providing refrigeration trucks for its members.

Farmer #4

"If 12 different farmers go to them and say write me up a check, it's a lot easier if we pool our stuff together where one delivery comes and they write one check. We have standards between us that have to be met so that it is comparable product."

Both farms used a similar number of machines but Farmer #1 used more labor and grew on more acreage. With respect to equipment use, it is hard to surmise if the fact that both share or have shared equipment is the reason why they have similar levels of machine use. Farm #1 has ten times the fruit and vegetable acreage of Farm #4. Farm #4 also borrows machinery heavily from a dealership meaning that it is difficult to determine if their entire machine fleet would remain at the farm if they did not have the borrowing arrangement. However, this did not mean that farmers in the case study did not see sharing was a way to reduce the cost of acquiring machinery. On the contrary Farmer #1 and #2 both saw sharing as potentially a good way to acquire machinery.

Farmer #1

"Sharing is a good thing to do if you can. You just have to find the right partner. Some things you can share, you can even share a tractor if you had to. But then you'd just have to work it out. Can I use it this day and then you use it that day and that's what's going to get tricky."

3.2.7.2 Farms Custom Hiring and Renting Machinery

Farmers #2, #5, and #6 all acquired machinery by custom hiring. These farms were similar in many respects including machine fleet size and labor usage. Farmers custom hired for similar reasons. Tasks that were customed out typically required larger and more expensive equipment were larger in scale and took place once over a growing season. All three farms custom hired neighbors to help with tillage on a larger scale and two out of the three custom-hired to help with spreading fertilizer. All three farmers cited that since these larger pieces of equipment were only going to be used once in a season, they would not be worth purchasing. Since these

Farmer #2

"Around here there are folks doing cooperative marketing, if you can agree on a price and a market and a way of selling your potatoes with your five neighbors growing potatoes also, it seems like it would be pretty easy to also share machinery. If you've already been able to come to that amount of agreement, it shouldn't be that hard to share a piece of machinery. Have some written agreement out so when something breaks, who's responsible for it or how do you share the costs on it or whatever. So I think there's a lot of potential there. I would love to see more cooperative ownership of machinery... The potato digger is a great example of that. I don't use it very much it is nice to have it when I need it but if someone else wanted to buy a share of that machine it would make sense."

pieces of equipment are common on row crop farms, it is easy to hire a neighbor to do the work for them. These custom arrangements have indeed made it cheaper for these farms to acquire machinery for these tasks.

Farmer #2

"When we first bought the land I hired the neighbor with a big plow to plow up the CRP ground that we could plant the gardens in. Since then it has just been the only machine work has been manure spreading... I always think about getting a small manure spreader and a bucket loader for my tractor so when they get in semi truckloads of compost I don't have to call my dealer to spread it, I can do it at my own leisure with my own equipment. But that's about all I would need those two implements for and so it's a big chunk of change to buy those two things for once a year. It's easier at this point to pay a neighbor a couple hundred bucks to come over and do it than to think about investing in those two things."

Farmer #5

"My brother in law, he's a big time corn and bean farmer and the 15 acre field and the 5 acre field, he'll come in the fall and disc it. And if he doesn't get it done in the fall he'll do it in the spring for me. So I do have that. I think it costs me like $100 for him to do that."

With respect to larger tillage equipment this arrangement makes sense. These implements are more commonly suited for farms that grow corn and soybeans, staple crops among Iowa farmers. This means that more than likely these implements and their operator are close to these farms and since they are larger in scale can cover the relatively smaller fruit and vegetable farms relatively quickly. This makes informal custom agreements a good way of acquiring the services of larger tillage equipment. Only one of the farms rented equipment but interestingly renting was not used to avoid fixed costs of ownership. Instead, Farmer #2 rented a potato digger as a way of trying it out before purchasing it. Instead of renting, Farmer #1 primarily asks for recommendations and borrows equipment before he finally purchases equipment.

Farmer #6

"For any year for everything that I could possibly want I'm not paying in more than $300... Any of the like larger primary tillage, flail mowing, if we're going to till up everything in the spring, we've got a neighbor that has a tractor, there are lots of people with those sorts of things and we can pay him. He'll come to till the whole farm for 30 bucks. If we need to turn in a cover crop, I've got a brush cutter I can chop the cover down with and then he can turn it in... it doesn't make sense for me to buy a $5000 tractor that can mow and till a field. I can pay my neighbor to do that. So it's trying to be strategic about when you implement those things."

Farmer #2

"For two years, yeah I just took my tractor and drove it down to the implement dealer three miles down the road and rented it for the day for 60 bucks or something and tried it here. I said well this is pretty slick it works better than the old one I've got. So the following year I was able to go in and purchase it."

3.2.7.3 Context Between Crops by Season and Perennial Types

All but one of the case farms had both warm and cool season crops and every farm grew at least one perennial crop in the set though not every farm had primary crops in each of these categories. Since Farmer #3 only grew a perennial crop he talked about perennial crop issues the most. Farmer #3 grows a perennial crop and has a limited set of machinery compared to the other case farmers. Since he only grows one crop this may contribute to the small size of his machine fleet. However, there are indications that perennial crops require fewer machines to raise them. By growing asparagus exclusively, Farmer #3 avoids tilling and seeding each year, tasks that on most farms account for a lot of mechanization. Most of the total hours on the farm are hand labor hours during harvesting and preparing the asparagus for customers. Although asparagus' harvesting schedule is relatively intensive, hand harvesting was common for most fruit and vegetable crops.

Farmer #1

"A lot of times I'll use a piece of equipment from someone and see how it works and if I like how it works then I'll either buy one. Test them out. If you can get someone to test, a friend or neighbor to let you borrow something."

Farmer #3

"He works until he's done, until he gets through the whole field... He stays about 8:30 and he'll quit about 6:00 at the end of the day... and I'll help probably if you added my time up too. It would be two hours probably twice a week for me and Maryanne probably would write that time off. And that's just picking that's not snapping it... everyday I probably put in about 3 hours of sorting and snapping... I think its starts and if you read stuff production starts dropping off after 20 years or something like that... Planting is the easy part, getting into it. People say how do you plant four acres, with that system I can plant that in two hours. Now if I had it all set up then it's just [easy]. So getting into asparagus production is really really easy... Asparagus is easy to get into and once its established and then from that point on, staying with it and doing it."

Farmer #1 also raises perennial crops including, coincidentally, the same acreage of asparagus as Farmer #3. These crops were brought up in the interview because they also happened to be cool crops that are raised in the early part of the year. In Iowa, the early spring is a wetter time of the year and this keeps the number of workable field hours for these crops low. Like Farmer #3, Farmer #1 also brought up that many of the tasks associated with these crops had to be completed by hand. This required that Farmer #1 hire extra workers in the beginning part of the year.

Farmer #1

"We start out in the spring. Our first crop is asparagus that's the first vegetable that comes up... a lot of times in the spring, you don't have that many good days to be outside working cause its either rain or raining. In the last couple of years hasn't been that way but some springs you maybe only have a day or two in a week and its going to be wet all the rest of the week so it will be hard to be out... Some crops I'm not afraid to go bigger on but there are certain crops like broccoli I'm a little bit leery on because it's just an early crop, you just have a short window... A lot of that [cool crops] is just done by hand... to hand plant or hand transplant."

Garlic was one of the primary crops for Farmer #2. Like asparagus for Farmer #3, garlic is also rather labor intensive, especially in harvesting. This type of crop has additional storage requirements. Garlic, like onions, also requires curing before it is sold. This helps preserve the crop and allows it to be sold consistently throughout the season in spite of a one-time harvest. Curing garlic requires a cool, dry area to hang it and in Farmer #2's case, this encouraged the purchase of a high tunnel.

Farmer #2

"We do a lot of garlic we got about almost a half-acre of garlic... I'll pay a couple extra people, day labor basically to help hand dig and clean the garlic and get it all into storage for curing... we harvest it all in Mid July. I just do it on a weekend after market on Saturday when I get home..."

More interesting to this study were the comments on crops and production-level considerations. Several farms cited that crop-specific production factors dictated crop selection. As shown in the literature, fruit and vegetable crops can vary quite a bit and categorizing crops by 'ease' of growing is highly subjective. For Farmer # 4, salad greens such as spinach were too labor intensive for them to produce. Farmer #6 produces salad greens essentially because no one else produces them to exploit price premiums and was willing to put up with the labor intensity.

Farmer #6

"... we managed his farm, learned his operation... We're not doing 60,000 pounds of beets a year or potatoes, or commodity based crops, we're niche, small, high value crops. Getting into those places and from there we'll have to see what happens. Go for the high dollar crops that we can do easily, that we can do for longer than most people can, and then expand that principle."

3.2.7.4 Farms with Other On-Farm Activities

For farmers that engage in other activities on the farm besides growing fruits and vegetables, acquiring machinery that apply to a broader range of activities may encourage acquisition. Case farmers tended to have mixed feelings on this. Farmer #1 said that his acres of corn and soybeans required that he have a larger tractor. This larger tractor was a good implement to have for his fruit and vegetable crops since he can use it for his initial tillage of all 50 of his acres. Farmer #3 also grows corn and soybeans but said that this was not the case. In some instances, larger equipment is not a option. Fruit and vegetable crops are in tighter rows and cannot take the soil compaction from larger equipment.

3.2.7.5 Scale and Scope

The original hypothesis is that farms that are more specialized will tend to purchase more machinery since it is better to achieve a higher level of economies of scale. Only Farmer #3 specialized in a single crop but this crop was a perennial meaning that two hypotheses went in opposite directions. Farm #3 had the smallest machine fleet in spite of being specialized. At first glance, this may make it difficult to determine if scale impacts machinery acquisition but a comparative analysis provides clues to scale's impact.

One measure of the degree of farm mechanization is the horsepower of the power units on the farm. The tractor with the highest horsepower in the case study was a 70 horsepower tractor owned by Farmer #1, the farm with the most acreage in fruits and vegetables. Interestingly, in spite of growing many crops, Farmer #1 has the highest number of acres dedicated to a single crop with 20 to 30 acres going towards sweet corn. By this measure, Farm #1 is clearly the most mechanized farm in the case study since it also has the tractor with the second largest horsepower as well as a third tractor. Farmer #5 has the second highest total fruit and vegetable acreage and the second highest acreage into a single crop with approximately 10 acres in sweet corn. Since he only owns a single 25 horsepower tractor, this seems to go against the hypothesis. However, this may not be the case. Farmer #5 obtained 15 acres relatively quickly and this meant that there was little money left over to scale up machinery.

Farmer #5

"The reason why I haven't bought [machinery], I purchased that 15 acres in 2009. So that was another $90,000 and lawyer fees and that pretty much said goodbye to another tractor and any new equipment... So that's the reason why. What I really need is a 70 horse [tractor] with a 20 foot disc cultivator, not as big as my brother in law's but I need something. That 15 acres, my little 25 horse tractor with a 5 foot tiller, it gets a workout for it and it's a time consuming."

Farmers #2 and #4 seem to continue this trend since both have the same number of acres and though their crops, though not identical, are similar to one another. Farmer #2 uses a 30 horsepower tractor and an 8 horsepower walk-behind rototiller as power units and Farmer #4 uses a four-wheeler and a 35 horsepower tractor is the primary power unit at their five-acre farm. Farmers #3 and #6 had the fewest fruit and vegetable acres. Farmer #6 had only a walking tractor as a power unit and these units generally range between 8 and 13 horsepower. Farmer #3 had only a small lawn tractor as a field power unit. Using horsepower as a measure of mechanization, increasing the scale of production tends to encourage the purchase of larger machinery.

Farmer #6

"I can manage most of it with just that walking tractor cause its just on a small scale."

Though there are incentives to purchase machinery when a farm scales up, this does not necessarily reduce the importance of labor on the farm. Farmer #3 said that he is not interested in increasing the scale of his asparagus production for several reasons including increasing labor. Growing four acres of asparagus requires a lot of hand labor hours. Increases in asparagus acreage would almost certainly require hiring more workers to help with harvesting. Farmer #3 also would need to find other outlets if he increases production. Farmer #2 is not interested in expanding acreage but is confident that making changes to his crop mix and purchasing machinery will increase his production. He admits however, that labor will still be important due to lack of alternatives to hand labor for certain tasks.

Farmer #3

"... I suppose if we had more then you just couldn't walk it all if you had more [acres] you'd have to have more people. Right now one person working everyday can do this for our acres... Well then also we're able to sell it but I don't know. What if we doubled production would we have a tough time selling it? I don't know we can sell everything we have now and that's kind of where we are."

Farmer #2

"... if I took and invested more in machinery I could maybe get rid of some of the labor, but not all certainly... The only way to get a green pepper off the plant is to take a person and cut it off, there's no machine for that... Most of the harvesting we do on this scale is handwork so there's not a really good way to mechanize some of that stuff. "

Mechanization's relationship to scope seems to be a bit more complex and mostly varied with the heterogeneity of the crop mix. Several growers cited that the amount of tasks that a machine could be used for was important consideration. Farmer #1 said that he uses the same tillage and planting equipment for sweet corn as he does for green beans but not for other vegetable varieties. Farmer #2 said that he uses mulching equipment for many different crops. Farmer #4 uses the same potato digger to harvest all of the root crops and their Jang planter has changeable plates. Farmer #5 said that he transplants several crops with his mechanical transplanter. This makes sense since if two crops are similar enough so that they require the exact same machines to raise them. In this case, increasing the sum of acreage for these similar crops mimics increasing the acreage of a single crop since the fixed machinery costs can be spread over more output.

Farmer #4

"The ecoweeder is very good, the next one as far as importance to our farm would be the potato planter because we use that for the potatoes, the gladiolas, the tulips, and the garlic."

Contrary to the results of the survey, as the farm's crop mix became more diverse, scope tended to discourage machinery use. The same farmers that seemed to purchase machines with a wider scope of crops also stated that they had trouble growing certain ones. For instance, Farmer #4 spaces certain flowers closer than his transplanter is able to plant so these are done by hand instead. Farmer #2 said that a more diverse crop mix lead him to hire more workers since he needed to carry out more tasks simultaneously. His level of crop diversity also discouraged the purchase of a transplanter.

Farmer #2

"I grow so many different things if I were actually growing acres of broccoli I would definitely have a transplanter that worked for the broccoli but since I remember doing a transplanting on a Monday, its ten different things I'm planting in a couple different beds you have kind of to redo the spacing and its like no let's just do it by hand."

3.2.7.6 Marketing Outlets

The way a farm markets its crops may impact machinery decisions. From the farmers' perspectives, marketing outlets differed in four ways: scale of production, the level of crop diversity, predictability, and prices. Direct marketing through CSAs and farmers' markets tended to offer price premiums compared to wholesale outlets. Direct outlets also required growers to offer a more diverse set of crops. Growers marketing through farmers' markets need to grow more types of crops so that they can sustain production throughout the entire market season. Since CSA customers typically receive an assortment of vegetables each week this, CSA growers also need to have a diverse crop set. Among direct sales outlets, CSAs offer the highest level of predictability. CSA customers sign up before the season starts and each week they receive baskets of comparable value. This makes it easier for CSA farmers to predict how much to produce and their CSA revenues. Farmers' markets are less predictable for growers since they do not know the level of weekly demand before they take their produce to the market. Wholesale outlets such as grocery stores and restaurants generally ask for a larger and more uniform set of crops. These outlets generally do not receive the price premiums that they would from direct selling.

Farmer #5

"You know how many members you have. You know that each member is going to get about $20 worth of produce... We make a list up we know exactly how many green beans to pick, its all picked its all put in boxes... By 4:30 about all their stuff is picked up, our day is not done but we sold about $400 worth of produce that day and its all taken care of and there's no waste... I wish people would sign up earlier, like in February or right like now. I mean we do have people calling us but we actually get more people signing up in May."

Farmer #6

"To some people, wholesale in tomatoes may mean $1.00 a pound to us that means $3.50 a pound, it's choosing markets. To be able to say we can justify the slightly lower costs. As long as we continue to find those markets, there's not a true premium retail value. If I can sell lettuce mix and spinach for $7.20 a pound wholesale and I can get $9.00 to $10.50 maybe at a farmers market, is it worth it? [Depends on] how much you're producing, where do you have to go for your markets all those things."

Since CSA customers receive a weekly allotment of produce of a standardized value and usually pay up front at the beginning of the season, this might give the grower the cash-on-hand as well as the certainty of production quotas to make more informed mechanization decisions. This idea extends to the more formal forms of wholesale marketing. Stated earlier, pricing and production quotas are more certain and the farmer will know the revenue impact of production. No farmer in the case study stated a direct connection between machinery acquisitions and marketing but they did say that cash flows were important. Farmers #1, #2, #5, #6 said that the amount cash-on-hand impacted the timing and, on certain farms, the selection of mechanical investment. Some farms cited that as a fruit and vegetable farm, obtaining credit from a bank was more difficult. These farms tended to reinvest most of the farm's profits into the machine fleet and other farm improvements.

Farmers' markets seem to be an important outlet for beginning fruit and vegetable farmers. Five out of the six case farms directly market through farmers' markets. Farmers #1, #2, #4, and #5 started with farmers' markets when they entered into commercial production. This is likely because at this stage, farmers likely do not have established relationships between CSA customers or produce managers of wholesale outlets. Farmers' markets aid in matching customers to new farmers that may not have these relationships by offering a place and time for them to meet each week. As the case farms became more established, they started branching into CSA and wholesale production.

Most of the wholesale outlets were through grocery stores or restaurants. These relationships rarely involved a formal contract but rather relationships between the farmer and the grocery store produce manager or chefs. This meant that for many growers, their deliveries to grocery stores are subject to some variation in volume and price. This may downplay the role that grocery wholesale outlets plays in machine investment decisions since it does not necessarily imply a consistent income within the season. From the discussions of the case farms, the input that marketing outlets seem to impact the most is labor hours. Different marketing outlets require different delivery systems to the customer. CSA farmers typically need to advertise in order to cultivate business each year. Farmers' markets require workers to man stands and transport produce to the market each week. Depending upon the arrangement, the farmer may have to make deliveries to wholesale or CSA customers or they may be picked up at the farm.

Farmer #1

"... some stores are better than others just because the produce managers say 'I like your produce or I like your sweet corn so I'll pay you this much... they can get a box of green beans for maybe say a dollar a pound and when there is a big glut of them they may go down to $12.00 for the whole box. But sometimes if you have relationship with the produce managers then they might not go down. They say 'I'd rather pay a little more and keep (you).' "

Farmer #6

"So we'll be the spring kale folks. We'll at least grow it then and if you find that she's getting it somewhere else then you don't then we hold onto it until there's a gap. Now we're to the point where she says 'anything that you can bring me early, I'll take and as long as you can continue to have it without a break, I'll take it from you until there is a break at which point then I'll probably go to somebody else if it's local.' ... Now with things like fall and winter spinach, that's just us... If we ran out, and there was somebody else, she would definitely use them as a filler but when we came back, we would have priority to that market."

To a degree, the marketing strategy also depended on the farmer's preference. Direct marketing requires more personal interaction than wholesale marketing. With respect to pricing and predictability, CSAs seemed to have the best of both worlds but they require additional time and expenses to attract customers and prepare orders. Outlets to an extent can impact the choice of crops. Wholesale outlets often require higher volumes of sustained production in a few key crops while CSAs and farmers' markets may require producing a more diverse but small-scale crop mix. Farmers #1, #4, #5, and #6 all described that not all marketing outlets ask for the same types of crops and stressed the importance of sufficient output demand for crops.

Farmer #1

"I see some people get discouraged because they just like to grow certain things say like brussel sprouts or beets or something like that. Well there is some but not a huge demand so you got to figure out what people want or develop your market so that you'll be an expert at growing some things that people want."

Farmer #5

"... I actually, by how many members I have kind of decide how many acres of lettuce, as a farmers market goes, carrots. Nobody buys carrots at farmers' market for some reason. I take them there, they don't buy them, they don't buy cabbage. At the CSA people love, it's the type of people. I have beautiful carrots a whole big bin of them but you can't sell them."

Farmer #6

"We haven't done any CSAs here to that point. We just don't have the time. I (don't) want to market it, to handle client interaction and any of those things. We want to be able to either call or email somebody and for them to tell us that they want "this, this, this, and this", we go out and harvest it and box it and deliver it. It's worth it to for us for the price that we've been able to find wholesale around here to do it that way."

3.2.7.7 Farmer Preferences and Constraints

Machine purchases for the case farms seemed to take place in two contexts, from a farm more or less following a template from previous employers and farms that carefully experimenting with what works on their farm. The prior group tended to justify purchases by saying things like "because I've seen this work for this similar farm" although as their model deviated from the standard model they cited many of the acquisition justifications in figure 2.2. For Farmers #2, #5, and #6, the primary crops, the machine fleet, and the production techniques were selected from what they knew from previous employment. These farmers had all worked for other growers before venturing out on their own.

Farmer #6

"I had been farming long enough that I knew exactly what (we needed). My wife and I, this has all been very strategic... The farm that I worked on... had tractors as well but that [walking tractors] was what we used everyday... we managed his farm, learned his operation."

Farmer #5

"the water wheel... I seen (my renter) had that and how quickly he had done it... I used it with (him) and helped him plant stuff and after I think about three years, I was getting big enough that I just really got tired of planting stuff by hand, my back and I was just tired."

Farmer #2

"The first four or five years in particular of doing our own stuff here both on rented land and when we moved over here, we very much basically started with their (the CSA's) model. We know what worked for them, lots of modifications of course. The size of plug flats that they used for growing lettuce, well let's start out with that... in the mid 90s they were experimenting with a mechanical transplanter. They sold it the next year, they decided they could transplant just as fast with (by hand)... So I never purchased a mechanical transplanter."

Farmer #1

"Well being as we grow field corn it was easy to transition into sweet corn and it was easy to transition into green beans... So I just saw that you can use a lot of our same equipment to plant a lot of this stuff. You can even plant pumpkins with our planters if you wanted. But they're different. So you just have to experiment, trial and error and what works and what doesn't."

Farmer #3

"We had two little gardens and we just figured it out this is the way to do it... I just grew it for other people and friends and it just got started and then 'wait a minute'. We kind of know more about this than a lot of people why don't we just try it..."

One of the goals of this study is to see if there were any constraints to mechanizing fruit and vegetable farms. Many farms were averse to taking out loans to purchase machinery so the amount of cash-on-hand often determined when machinery investments were made. For a variety of reasons growers were dissuaded from purchasing certain machines. Certain machines did not offer enough savings in costs, labor, or time to justify their purchase. Both Farmer #2 and Farmer #6 cited that compost equipment such as spreaders and bucket loaders did not offer sufficient savings. Some pieces of machinery require production changes that kept growers from purchasing them. To make multiple crops easier to produce with their machine fleets, case farmers had to adopt standardized production practices such as setting row widths for multiple crops. The use of certain machines would require changing these practices. Sometimes preferences also dictated machinery purchases. Farmer #3 decided to sell his asparagus harvester due to preferences.

Farmer #4

"... with our tractor, two row equipment does not work either because it's too narrow to have the two rows and you're driving over something. And trying to dig potatoes on something that you drove over... Is not fun... One row works best for us. If we had a wider tractor, we may consider the two."

3.2.7.8 Case Study Conclusions

Testimony from the case farms highlights the importance of context in farm expansions. Farms formed their expansion and input strategies based on their previous employment or through gradual trial-and-error. Farms producing large quantities of similar crops tended to use more and larger pieces of equipment. Those that grew a more diverse set of crops tended to use more labor. This is important for modeling farm expansions since it indicates that machines and crop tasks should be matched together to be realistic. Mechanization helped offset labor costs but did not completely eliminate the need for labor entirely.

Compared with the survey, the case study was also able to provide greater detail about farm crops, tasks, and machinery and how they evolved throughout their expansions. This identifies typical machines and the crops that farmers use and grow. This information is vital for constructing simulations since it identifies machines, the crops, and the tasks should be included. For most above ground crops, harvesting still remains a labor intensive task. Farmers sold their crops in several ways. This shows that machine purchases will not impact the required labor hours for such tasks. These tasks should not be as rigorously examined in models with binding size constraints that are specifically considering labor-machinery tradeoffs. Detailed accounts of expansions provide useful ex ante and ex post facto context that aids in determining if model results are reasonable and needed changes to improve accuracy.

CHAPTER 4. MODEL METHODS AND DESIGN

4.1 Model Concepts and Justification

A model that performs a cost-benefit analysis for a machine purchase is fairly complex. Some machines such as a potato digger can be used to perform tasks on several crops such as flower bulbs, carrots, and other below-ground crops. Other machines are specific to one particular task such as green bean picker. Still other crops lack any mechanical alternatives to hand labor for certain tasks. An additional complication that is more unique to smaller scaled local agriculture is the fact that produce can be marketed in several different ways. Standard row crops such as corn or wheat are sold nearly exclusively through elevators at close to perfectly competitive market prices. On the other hand, local growers sell fruits and vegetables directly through farmers markets and roadside stands, through wholesale outlets such as grocery stores and through auctions to name just a few ways. Fruit and vegetable prices like other crop prices vary not only throughout the season, but also by location and crop type. Finally, the concept of timeliness cost is critical (Edwards (2009); Landers (2000); Hunt (2001)). Timeliness costs are essentially the costs of not performing certain tasks within an optimal time window. One of the main reasons that timeliness is important to farms is that weather impacts the development of plants. If a crop like sweet corn is planted too late in the season, it will not be able to absorb the needed heat units throughout its life to achieve maximum yield before a harvest (Edwards (2009)). For many farms, the summer is a busier part of the growing season. Since many farms in the survey and the case study grew more than one crop, it is possible that several of these crops could be vying for the time of a single implement over a busy time. Since this is the case, a model should take into account how much a machine will be used over the course of a growing season as well as when it will be used.

The first complication dictates that a generic model must take every task on the farm relating to production into account. The model must also include every piece of farm equipment both currently used and considered for purchase as well as hand labor and match each equipment type to each task. While not all of these machine-to-task matches will matter, the model must be able to handle the possibility that more than one machine is suited for the same task or that a single machine can perform multiple tasks. The second complication of the multiple marketing outlets makes it very difficult to simulate profits. A farm growing grain crops is generally subject to observable market prices. Such prices, although not known with certainty, are at the very least exogenous in the profit function and sensitivity analysis could accompany a profit-maximizing model of this type. Local fruit and vegetable producers on the other hand, have many options for marketing their output. Within the interviews, it was frequently stated that goods at farmers markets fetch higher prices than the same goods from wholesale markets such as grocery stores. In one interview, it was even mentioned that market failures such as price fixing was present at farmers' markets. Furthermore, prices for goods vary widely over the year. Some farmers like Farmer #6 in the case study make efforts to specifically time production so as to catch markets during low production months. To reduce the complexity, cost minimization will be the goal of the model. In this research, the modeler assumes that a farmer is aware of the projected revenue an expansion will yield. The assumption follows that if the farmer is able to complete the farm's tasks within their respective optimal time periods, the farm will generate a known level of revenue. Viewing the farm's profit maximization problem in this way, the farm will maximize profits by minimizing the costs associated with completing all of the considered farm tasks within their respective optimal time periods.

The last area of complexity, timeliness, was an important concept in the literature. This suggests the model should have a dynamic element, similar to the profile charts in Landers's book (Figure 1.3). The profile charts, though useful for identifying busy times of the growing season, are a bit too simplistic to be used in an optimization model. This is because instead of placing the optimal number of hours in each period, profile charts apply the average number of hours needed to complete a task homogeneously throughout the optimal time window. Consider a simple example of a farm that has only two tasks to complete, task α and task β, over two days with a single machine. In a given day, the machine can not operate for longer than eight hours, the length of a standard work day. The machine has an efficiency rate for each task equal to the number of hours that are required to complete one acre of the task. Consider the following conditions (Table 4.1). Under a standard machine profile chart, the amount of hours the machine will apply to each task in each optimal day will be $\frac{[Task\ i\ Acreage]\times[Task\ i\ Machine\ Efficiency]}{\sum Optimal\ Task\ i\ days}$. The profile chart produced from these values will allocate two machine hours in the first day and ten machine hours in the second day violating the daily machine hourly constraint (Figure 4.1). This simple example shows the limitation of the hourly profile chart. Over the two days, the machine is run a total of 12 hours, less than the 16 hours the machine is able run over the two days. If the farmer were able to reallocate hours within the optimal time intervals, he would be able to meet the daily hour limit of the machine (Figure 4.2). Put simply, if the farmer knows that a busy period is approaching, he will try to work ahead or put off work as he is able so he can get through the busy period. It is clear from this example that a dynamic optimization model is needed to allocate machine hours throughout the season.

Table 4.1: Machine Profile Chart Descriptive Example

	Binary Optimal Variable				
	Optimal Day #1	Optimal Day #2	Task Acreage	Machine Efficiency (hours/acre)	Optimal Day Hourly Allocation
Task α	1	1	12	$\frac{1}{3}$	$\frac{12\times\frac{1}{3}}{2}=2$
Task β	0	1	16	$\frac{1}{2}$	$\frac{16\times\frac{1}{2}}{1}=8$

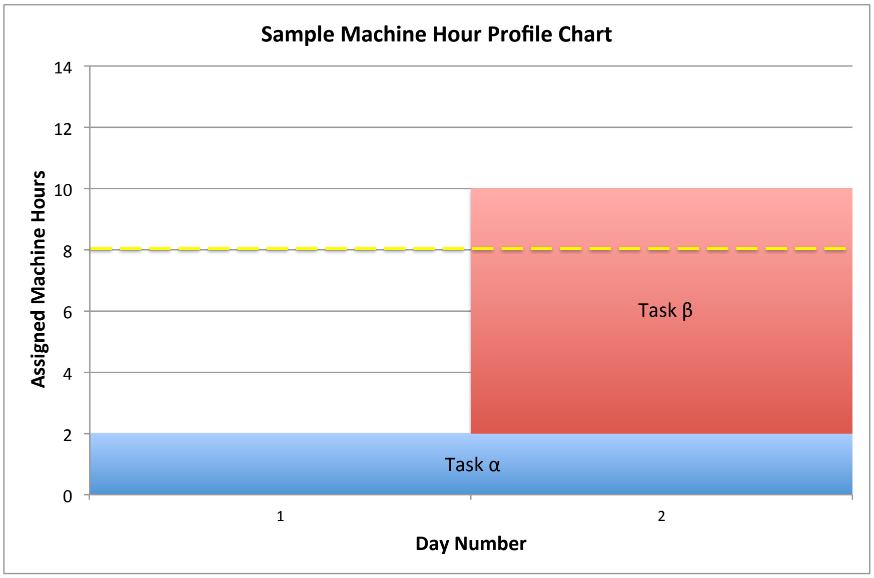

Figure 4.1: Unadjusted Machine Profile Chart

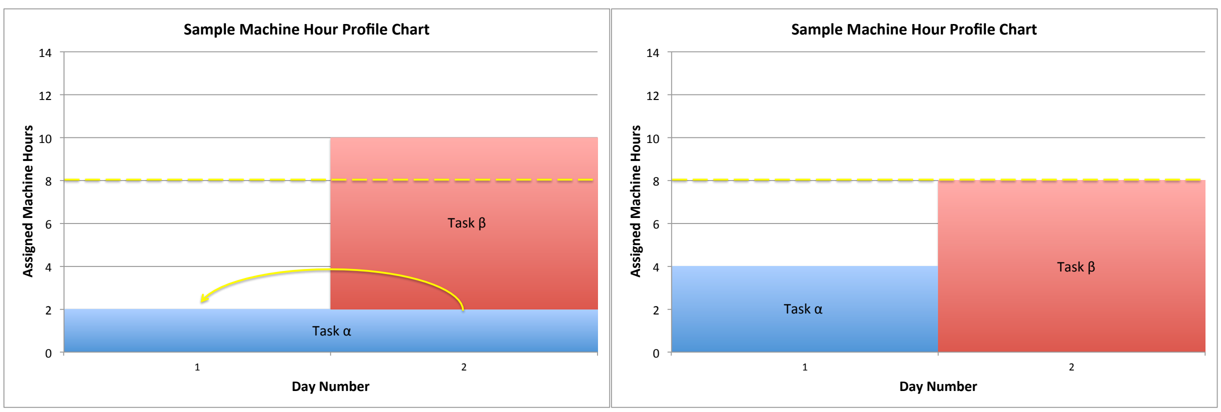

Figure 4.2: Adjusted Machine Profile Chart

4.2 A Brief Introduction to Dynamic Optimization Models

Dynamic optimization models take several forms. Two of these forms are predominantly used in continuous time problems, those in a calculus of variation format and those in a optimal control theory format. These models have seen application in the agricultural economics within crop rotation decision-making research. Since our analysis takes place in discrete time and these models require additional assumptions, these models will not be covered in this paper. The other two forms of the dynamic optimization generally consider discrete time problems;

these are the Lagrangian form and the dynamic programming form. Both models in fact use the same backward-looking recursive mechanism for determining an optimal path. Since the Lagrangian method is a more natural extension of standard microeconomic analysis, this paper will use this method.

All dynamic optimization models have two types of variables that are involved, decision variables ($\mathbf{a}$) and state variables ($\mathbf{s}$). Notice that the decision variable and the state variable symbols are bolded, meaning that they can be vectors. Decision variables are essentially the choices that the decision maker makes throughout time. In our model, the decision variables are the hours that the farmer applies for each machine and hand labor for each task at a given period of time. The state variable represents the "state of the world" at a given period of time. In the current model, a state variable would be the acreage remaining to be completed for a given task on the farm at a given period of time. In addition to identifying the choices and states, the dynamic optimization model must be able to assign values for the choices that the farmer makes. The contemporaneous return function $f(\mathbf{a}, \mathbf{s})$ assigns values for the decision variable at a given state. Additionally, the model must be able to recognize how the state of the world changes as decisions are made over time. The transition function $g(\mathbf{a}, \mathbf{s})$ explicitly makes this transformation given the action that was taken and the state of the world in the previous period. In our problem, the contemporaneous return function will be the additional cost of applying the hours to given tasks within the period and the transition function is the change in the remaining task acreage values after the hours are applied. Generally dynamic optimization environments take on a concise form (Algorithm 1[1]). The choice of each decision variable creates a contemporaneous return from the action and also dictates the next state of the world.

The Lagrangian with the goal of cost minimization takes on a familiar form where β is a discount factor where $0 < \beta \leq 1$. Since this is a minimization problem, we need to minimize the total contemporaneous cost terms $f_t(\mathbf{a}_t, \mathbf{s}_t)$ where t is the time period index from 0 to $T-1$ and the final period's return $v(\mathbf{s}_T)$. Note that the final period's return function is not a function

[1]This figure was taken from Chapter 7 of Michael Carter's Foundations of Mathematical Economics. (Carter (2001))

of an action variable since this final transition function is determined in period $T-1$. Like normal constrained optimization problems, the cost minimization problem is constrained but in this case the constraints take the form of the identity of the transition equation in each period. The summation terms can be rewritten to make the first order conditions easier to determine and interpret. This is done through manipulating the summation in equation 4.1. The first one separates out the summation of the constraints into two summation terms, and then moves the final period's return to the end of the equation. The next step sheds the first term off of the contemporaneous return summation and places it at the beginning of the right hand side of the equation. The third step re-indexes the transition summation and peels off the final term in the state variable summation. Careful observation will show that this re-index of the transition summation does not change the value of the summation. The final manipulation is to peel the first term of the transition summation and place it near the beginning of the right hand side of the equation. This manipulation accomplished making every summation sum time periods from zero to $T-1$ and made it so the generic form sums all action, state, transition, and return variables in terms of a common period t.

$$\begin{array}{ccccccccc} & \mathbf{a}_0 & & \mathbf{a}_1 & & \mathbf{a}_2 & & \mathbf{a}_{T-1} & \\ \mathbf{s_0} & \longrightarrow & \mathbf{s}_1 & \longrightarrow & \mathbf{s}_2 & \longrightarrow & \cdots & \longrightarrow & \mathbf{s}_T \\ & \downarrow & & \downarrow & & \downarrow & & \downarrow & \downarrow \\ & f_0(\mathbf{a_0},\mathbf{s_0}) & & f_1(\mathbf{a_1},\mathbf{s_1}) & & f_2(\mathbf{a_2},\mathbf{s_2}) & & f_{T-1}(\mathbf{a_{T-1}},\mathbf{s_{T-1}}) & v(\mathbf{s}_T) \end{array}$$

$$s.t.\ s_{t+1} = g_t(\mathbf{a}_t,\mathbf{s}_t)\ for\ t = 0,1,\cdots,T-1$$

Algorithm 1 The Standard Dynamic Optimization Environment

$$\min_{\mathbf{a_t},\mathbf{s}_t} \sum_{t=0}^{T-1} f_t(\mathbf{a_t},\mathbf{s_t}) + v(\mathbf{s}_T)\ :\ \mathscr{L} = \sum_{t=0}^{T-1} \beta^t f_t(\mathbf{a}_t,\mathbf{s}_t) + \beta^T v(\mathbf{s}_T) - \sum_{t=1}^{T} \lambda_t \beta^t [g_{t-1}(\mathbf{a}_{t-1},\mathbf{s}_{t-1}) - \mathbf{s}_t] \tag{4.1}$$

$$\mathscr{L} = \sum_{t=0}^{T-1} \beta^t f_t(\mathbf{a}_t,\mathbf{s}_t) - \sum_{t=1}^{T} \lambda_t \beta^t g_{t-1}(\mathbf{a}_{t-1},\mathbf{s}_{t-1}) + \sum_{t=1}^{T} \lambda_t \beta^t \mathbf{s}_t + \beta^T v(\mathbf{s}_T)$$

$$\mathscr{L} = f(\mathbf{a}_0,\mathbf{s}_0) + \sum_{t=1}^{T-1} \beta^t f_t(\mathbf{a}_t,\mathbf{s}_t) - \sum_{t=1}^{T} \lambda_t \beta^t g_{t-1}(\mathbf{a}_{t-1},\mathbf{s}_{t-1}) + \sum_{t=1}^{T} \lambda_t \beta^t \mathbf{s}_t + \beta^T v(\mathbf{s}_T)$$

$$\mathscr{L} = f(\mathbf{a}_0, \mathbf{s}_0) + \sum_{t=1}^{T-1} \beta^t f_t(\mathbf{a}_t, \mathbf{s}_t) - \sum_{t=0}^{T-1} \lambda_{t+1}\beta^{t+1} g_t(\mathbf{a}_t, \mathbf{s}_t) + \sum_{t=1}^{T-1} \lambda_t \beta^t \mathbf{s}_t + \lambda_T \beta^T \mathbf{s}_T + \beta^T v(\mathbf{s}_T)$$

$$\mathscr{L} = f(\mathbf{a}_0, \mathbf{s}_0) - \lambda_1 \beta^1 g_0(\mathbf{a}_0, \mathbf{s}_0) + \sum_{t=1}^{T-1} \beta^t f_t(\mathbf{a}_t, \mathbf{s}_t) - \sum_{t=1}^{T-1} \lambda_{t+1}\beta^{t+1} g_t(\mathbf{a}_t, \mathbf{s}_t) + \sum_{t=1}^{T-1} \lambda_t \beta^t \mathbf{s}_t + \lambda_T \beta^T \mathbf{s}_T + \beta^T v(\mathbf{s}_T)$$

$$\mathscr{L} = f(\mathbf{a}_0, \mathbf{s}_0) - \lambda_1 \beta^1 g_0(\mathbf{a}_0, \mathbf{s}_0) + \sum_{t=1}^{T-1} \left[\beta^t f_t(\mathbf{a}_t, \mathbf{s}_t) - \lambda_{t+1}\beta^{t+1} g_t(\mathbf{a}_t, \mathbf{s}_t) + \lambda_t \beta^t \mathbf{s}_t\right] + \lambda_T \beta^T \mathbf{s}_T + \beta^T v(\mathbf{s}_T) \tag{4.2}$$

If the farmer is trying to minimize the total cost of production within a growing season, he will need to optimize the Lagrangian with respect to all of the variables that are under his control. The initial state of the world ($\mathbf{s}_0$) is assumed to be given exogenously. For farm models, this initial state will be the acres for each task at the beginning of the growing season. The remaining state variables and the decision variables are under the control of the farmer by virtue of the transition equation. This means that a farmer must satisfy the following first order conditions in order to minimize the production costs. To simplify the notation, $D_{\mathbf{a_t}}$ denotes the change in one of the action variables. $D_{\mathbf{a_t}} f_t$ is the change in the contemporaneous cost from applying an additional machine hour to a particular task at time t. $D_{\mathbf{a_t}} g_t$ is the change in the acreage left for the next period from applying an additional machine hour to a particular task at time t. As in other optimization problems, the decisions must be made so that infinitesimal reallocations result a zero change in the season's cost function. This yields the following three equations.

$$\frac{\partial \mathscr{L}}{\partial \mathbf{a_t}} = \beta^t D_{\mathbf{a}_t} f_t - \lambda_{t+1}\beta^{t+1} D_{\mathbf{a}_t} g_t = 0 \ : \ t = 0, 1, \ldots, T-1 \tag{4.3}$$

$$\Rightarrow D_{\mathbf{a}_t} f_t = \lambda_{t+1} \beta D_{\mathbf{a}_t} g_t \ : \ t = 0, 1, \ldots, T-1$$

$$\frac{\partial \mathscr{L}}{\partial \mathbf{s_t}} = \beta^t D_{\mathbf{s}_t} f_t - \lambda_{t+1}\beta^{t+1} D_{\mathbf{s}_t} g_t + \lambda_t \beta^t = 0 \ : \ t = 1, 2, \ldots, T-1 \tag{4.4}$$

$$\Rightarrow D_{\mathbf{s}_t} f_t + \lambda_t = \lambda_{t+1} \beta D_{\mathbf{s}_t} g_t \ : \ t = 1, 2, \ldots, T-1$$

$$\frac{\partial \mathscr{L}}{\partial \mathbf{s}_T} = \lambda_T \beta^T + \beta^T v'(\mathbf{s}_T) = 0 \tag{4.5}$$

$$\Rightarrow \lambda_T + v'(\mathbf{s}_T) = 0$$

In the Lagrangian form of the problem, λ_t values represent the shadow prices of relaxing the transition equation. The first order condition, Equation 4.3 states that when a farmer is optimally allocating its machine hours, the marginal return should equal the marginal cost associated with allocating an hour in the current period instead of the following period. When a farmer delegates an hour of machine time to a task at time t, he incurs the cost of using the machine ($D_{\mathbf{a_t}} f_t$) but also completes some of the task's acreage ($D_{\mathbf{a_t}} g_t$). The first equation states that the additional cost must be equal to the discounted value of reducing the acreage that they have left to complete at every point in time.

Because this is a temporal model, task acreage can be completed at different times. This means that the value of saving acreage for the next period must have equal consequences across time periods. If this were not the case, then the farmer could reallocate acreage over time to be better off. This is exactly what the second first order condition states. What happens if a farmer has more acreage to be completed in periods $[t,\ T-1]$? In certain problems this could impact the contemporaneous costs $D_{\mathbf{s}_t} f_t$. It also, of course, increases the acreage needed to be completed in periods $[t,\ T-1]$ meaning that the farm loses out value of reducing the acreage in period t (λ_t). Increasing the acreage left to complete in periods $[t,\ T-1]$ also impacts the down-the-line acreage yet to complete in subsequent periods $[t+1,\ T-1]$ ($D_{\mathbf{s}_t} g_t = D_{\mathbf{s}_t} s_{t+1}(s_t)$). Since the λ_{t+1} is measures the shadow price of relaxing the acreage in the next period, this first order condition governs the values these values take on. A shorter time horizon will increase these values because the model parameters dictate that the task acreage will need to be completed in a relatively shorter period of time.

The final first order condition is the marginal value of the having the acreage left over. If there is an additional acre left over at the end of the period, this last equality is usually meant to represent scrap value of inputs used in production. Unused acreage is not useful at the end of the growing season making $v'(\mathbf{s}_T) = 0 \Leftrightarrow \lambda_T = 0$. Additionally, each transition function is a function of every transition that came before it. This means that every decision that is made in the past impacts every future period's state.

$$\mathbf{s}_{t+1} = g_t(\mathbf{a}_t, \mathbf{s}_t) \Rightarrow \mathbf{s}_{t+2} = g_{t+1}(\mathbf{a}_{t+1},\ g_t(\mathbf{a}_t, \mathbf{s}_t)) \Rightarrow \mathbf{s}_{t+3} = g_{t+2}(\mathbf{a}_{t+2},\ g_{t+1}(\mathbf{a}_{t+1},\ g_t(\mathbf{a}_t, \mathbf{s}_t))) \cdots$$

The final attributes of all dynamic optimization models are called the transversality conditions. These conditions represent the initial state of the world and the desired state of the world at the end of the planning horizon. Under the current problem, these would constitute the initial acreage of each task and a series of zeroes since the goal for this model is for the farm to *complete* all of its tasks over the course of the growing season at a minimized cost. The introduction of these terms, though straightforward, creates complications that must be addressed. Transversality conditions can be made extreme enough so that the current machine fleet and pool of labor the farm has on hand will not be able to satisfy them. The previous simple example can again describe this if we consider an acreage profile that takes on more extreme values (Table 4.2). As before, these acres violate the periodic hourly constraint and the farmer will have to reallocate hours over time (Figure 4.3). However, with his current machine fleet the farmer will not be able to complete all of the tasks in their allotted time with the new acreage values. This is because the 18 hours that are required by the machine to complete both tasks and over the two days, the machine may only work a total of 16 hours according to the constraint that a machine's running time can not exceed an 8 hour work day. This means that there is no intertemporal reallocation that will allow the machine to complete both tasks in the allotted time (Figure 4.4).

Table 4.2: An Infeasible Acreage Profile Example

	Binary Optimal Variable				
	Optimal Day #1	Optimal Day #2	Task Acreage	Machine Efficiency (hrs/ acre)	Optimal Day Hourly Allocation
Task α	1	1	**30**	$\frac{1}{3}$	$\frac{30\times\frac{1}{3}}{2} = 5$
Task β	0	1	16	$\frac{1}{2}$	$\frac{16\times\frac{1}{2}}{1} = 8$

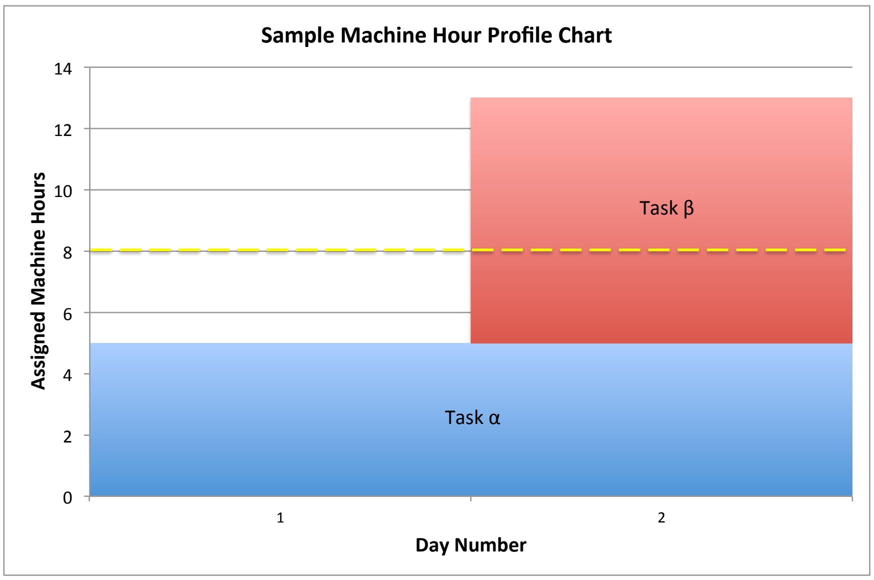

Figure 4.3: An Infeasible Machine Profile Chart

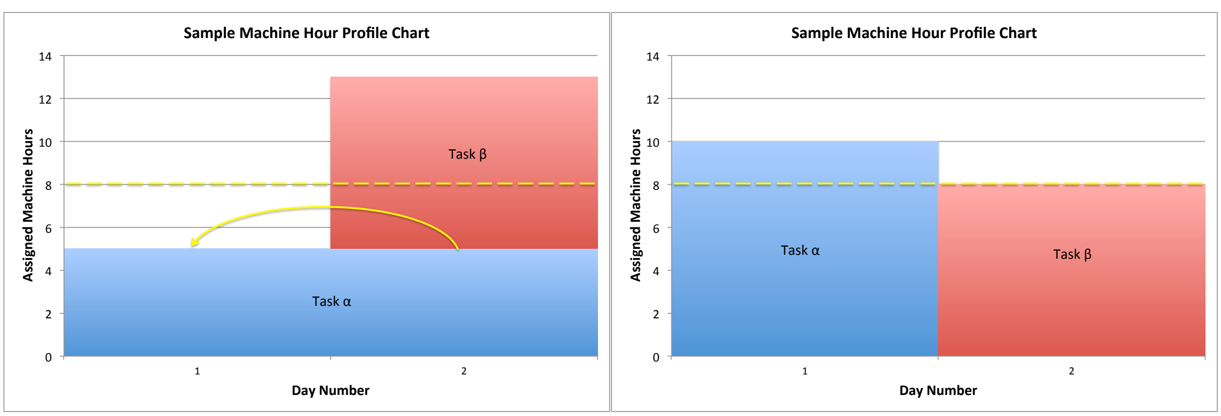

Figure 4.4: An Infeasible Hourly Reallocation

Above all, we want the model to be able to complete all of the tasks that is assigned within their optimal time intervals. This is because one of the outputs of the model will ultimately be the minimized production costs, a term that will be used to compare against the minimized costs under purchasing conditions. Cost comparisons will not be possible if the transversality conditions of the dynamic optimization problem are violated. Since the primary goal of the model is to determine if a machine purchase is economical, the alternatives to machine purchases must be added into the model. The primary alternative to machine hours that will be considered is hand labor hours[2]. With this in mind, in order for the model to produce cost comparisons for every acreage possibility, the labor pool must be able to infinitely expand if need be. Although this is not always realistic, the primary focus of the model is not to manage labor but to provide cost comparisons of having versus not having a particular machine. The only instance where comparisons are not possible is in the case is when an expansion adds a task that can not be performed by hand labor and the farm does not own the machine that is required to perform the prospective task. This is because there are no alternative actions to acquiring the machinery.

4.3 The Functional Form

The goal is to set up a generic version of the previous example that can accommodate more machines, time periods, crops, and tasks. Time periods are indexed by t such that $t = 0 \dots T$. Machines are indexed by m such that $m = 1 \dots M$. To better be able to match tasks to machines in the modeling process, they are described by two indices, crops indexed by v and actions indexed by a. For instance the crop "apples" and the action "harvesting" describes the task "harvesting apples". These indices will later take on a single index where $(v, a) = 1 \dots K$. The formal definition of the original endogenous variables "choice" variables from the simple example will take the form $MH(v, a, m)_t$. This variable specifies the number of machine m hours that are used to execute task (v, a) at time t. Since it is possible for labor to complete a task unassisted by a machine, $UH(v, a)_t$ describes the number of labor hours used to execute task (v, a) at time t that is unassisted by machinery. The final endogenous variable in the model

[2] There are obviously other alternatives to purchasing machines such as renting machines or custom hiring. For now these alternatives will be left out of the model but can show up in further iterations of the model. We leave this as an extension of the model for future research.

is the acreage remainder terms $R(v,a)_t$. This variable states the number of acres of task (v,a) are left over after period t.

The model must first be able to recognize whether pieces of equipment are appropriate for carrying out specific tasks. For example, the model must recognize that a pull-type seeder is not able to harvest apples. For this problem, the model uses the exogenous variables, the machine usefulness variable $U(v,a,m)$ and the labor feasibility variable $F(v,a)$. Both of these variables are binary to show whether a particular machine m or unmechanized labor is appropriate for carrying out task (v,a).

$$U(v,a,m) = \begin{cases} 1: \; Machine\ m\ can\ be\ used\ to\ complete\ TASK(v,a) \\ 0: \; Machine\ m\ can\ not\ be\ used\ to\ complete\ TASK(v,a) \end{cases} \tag{4.6}$$

$$F(v,a) = \begin{cases} 1: \; Hand\ labor\ can\ be\ used\ to\ complete\ TASK(v,a) \\ 0: \; Hand\ labor\ can\ not\ be\ used\ to\ complete\ TASK(v,a) \end{cases} \tag{4.7}$$

The model requires terms that are able to translate the hourly endogenous variables $MH(v,a,m)_t$ and $UH(v,a)_t$ into values that represent how much of the task is completed in terms of acreage. Such terms are the machine efficiency $E(v,a,m)$ and the labor productivity $P(v,a)$ terms. $E(v,a,m)$ represents the number of machine m hours required to complete one acre of $TASK(v,a)$ and $P(v,a)$ is the number of unmechanized labor hours required to complete one acre of $TASK(v,a)$. Efficiency rates are obtained from Iowa State University's Ag Decision Maker tool 'Estimating the Field Capacity of Farm Machines'. This tool estimates required hours per acre for a variety of implements and equipment however, some equipment that is more specific to fruits and vegetable production and unmechanized labor hours are omitted (Edwards (2012a)). These terms are useful in the sense that if a farm is considering purchasing a piece of equipment these values could provide estimations of the field efficiency of the machines. It must be stressed however that even subtle differences in soil composition and the shape of the fields can impact these terms. Standardized values can be as much 50% of actual values if factors such as field size, soil, and shape are not accounted for (Landers (2000) pp. 24-35). With this in mind, it is important to use a farmer's own data whenever possible. These custom efficiency and productivity terms can come from a simple field diary stating the number of acres completed with a given machine or work team over a given number of hours. Equipment and labor efficiency values for more specific pieces of equipment may need to be determined by calculating theoretical machine work rates or through extension services. $E(v,a,m,U)$ is described in this way since a machine not suited to perform a particular $TASK(v,a)$ could hypothetically allocate an infinite amount of hours and still not complete one acre of a $TASK(v,a)$. It should also be noted that there does not exist a machine that has infinite efficiency where a machine does not need to provide any hours to complete one acre of $TASK(v,a)$.

$$E(v,a,m,U) = \begin{cases} Machine(m)\ hours\ needed\ to\ complete\ 1\ acre\ of\ TASK(v,a)\ if\ U(v,a,m) = 1 \\ 0\ if\ U(v,a,m) = 0 \end{cases} \tag{4.8}$$

$$P(v,a) = \begin{cases} Unmechanized\ labor\ hours\ needed\ to\ complete\ 1\ acre\ of\ TASK(v,a)\ if\ F(v,a) = 1 \\ 0\ if\ F(v,a) = 0 \end{cases} \tag{4.9}$$

Stated earlier, the model must be able to recognize the time windows in which a particular task can be optimally executed. The optimal time variable $O(v,a)_t$ is a binary variable that specifies whether a given $TASK(v,a)$ can be optimally executed in period t.

$$O(v,a)_t = \begin{cases} 1:\ performing\ TASK(v,a)\ is\ optimal\ at\ time\ t \\ 0:\ performing\ TASK(v,a)\ is\ not\ optimal\ at\ time\ t \end{cases} \tag{4.10}$$

Many of these values are available through gardening and extension websites for planting and harvesting a variety of crops in the region. However, for tasks such as tilling or pruning standard figures are not well published. There are two alternative ways of producing the optimal values. The first is to simply use the farmer's crop set and machine fleet and the efficiency terms and let these optimal period terms be a function of them. Essentially if we want to plant by a certain day, the farmer must have tilling completed by that day. By taking a tiller's efficiency in hours per acre and multiplying it by the number of acres it has to till a certain crop, and then dividing this term by the number of hours in a work week, we can determine how many weeks in advance it is crucial to have tilling completed for instance. A second method of determining these optimal period terms is to simply ask farmers for their own preferences of optimal time periods. The most comprehensive standard calendar to the author's knowledge comes from the website GardenAction since it supplies location specific information for a variety of crops and a variety of tasks (GardenAction (2011)).

Usually machinery must be accompanied by labor to operate it and make necessary repairs and maintenance throughout the course of the growing season. To reflect the interaction of labor and machinery working together to complete a task we require a certain number of workers to accompany a machine throughout the growing season. Each machine m has two variables associated with it, the number of workers needed to operated it $N(v, a, m)$ and the proportion of each operating hour that has a laborer associated with it $T(v, a, m)$. Some pieces of equipment such as transplanters or varieties of potato diggers require a worker to drive a tractor to pull the implement and other workers assist the mechanism. It is assumed that if a machine breaks down temporarily in the field, all of those accompanying the machine are left idle. If a machine is especially prone to break downs, the proportion of running time that workers are associated with a machine may be well above 1. Note, these figures do not reflect the labor required to maintain the machine in the off-season or if the machinery is taken out of the field. With $N(v, a, m)$ and $T(v, a, m)$ in mind, we can describe the machine (m) assisted labor for task (v, a) at time (t) in the following form.

$$Machine\ Assisted\ Labor = MH(v, a, m)_t \times N(v, a, m) \times T(v, a, m)$$

The model will also have to include the costs of running a machine for a single hour $EC(m)$. We use Iowa State's Ag Decision Maker 'Machine Cost Calculator' model to estimate the operating costs of a machine per acre of use given current fuel prices, repair costs, and labor costs (Edwards (2012b)). With this, we can divide this term by the machine efficiency to generate the costs per hour for a particular $TASK(v, a)$ and a particular machine (m). Because it assesses hours of unmechanized labor hours and machine-assisted labor hours, this model is capable of differentiating between wages of field hands that perform tasks by hand $HW(v, a)$ and those that operate machinery $MW(v, a, m)$. However, we assume they are paid the same amount for now.

Now that we have our endogenous variables that make up the general model, we can define the specific information that the farmers will need to input into the model in order to determine allocation farm tasks. First, farmers will need to input the amount of acreage that must be completed $ACRE(v, a)$. It will be assumed that the acreage for all of the tasks associated with a crop will be same as the crop's acreage. For example, if a farm grows 10 acres of sweet corn, it will be assumed that it will need to till 10 acres for the sweet corn, plant 10 acres of sweet corn, and harvest 10 acres of sweet corn. Secondly, farmers will need to input what is in their fleet of machinery. The variable $Z(m)$ will show how many machines of type (m) they currently have in their machine fleet.

Recall that one of the principle components of a dynamic optimization problem is the contemporaneous return function $f_t(\mathbf{a}_t, \mathbf{s}_t)$. This is the total cost of labor and machinery costs for all of the fruit and vegetable related tasks in a given period. The goal is to minimize the sum of these costs over the growing season by applying machine and labor hours adequately throughout the season to complete every task at the lowest cost to the farmer. In this context, the applied machine hours and the hand labor hours are the decision variables. The contemporaneous cost function takes on the following form:

$$f_t(\mathbf{a}_t, \mathbf{s}_t) = \sum_{(v,a)=1}^{K} [\sum_{m=1}^{M} [MH(v, a, m)_t \times (EC(v, a, m) + N(v, a) \times T(v, a) \times MW)] + UH(v, a)_t \times HW] \tag{4.11}$$

The state variables are the task acreage terms that are left uncompleted at the beginning of a given period, also known as the remaining acreage ($R(v,a)_t$). As machine and labor hours are delegated to completing these tasks, these remaining acreage terms go down over time. The transition equation for the dynamic optimization problem represents this. The justification for the somewhat cumbersome form of the transition equation is needed to tell the model that by delegating machine or labor hours to a particular task that the machine or labor can not perform, approximately zero acreage will completed. Notice that the denominator for the negative terms are linear combination of the usefulness binary variables for machines and the feasibility binary variables for the hand labor. Consider the instance that machine (m) is appropriate for performing $TASK(v,a)$ then the respective machine (m) term will be $\frac{1}{E(v,a,m)}$. This term equals the acres of $TASK(v,a)$ that are completed for each hour that machine (m) is used. If machine (m) is not appropriate for performing $TASK(v,a)$ then the respective machine (m) term will be $\frac{1}{Q \times 2000 \times [\max_m(z_m)+1]}$. Recall that the maximum amount of hours that a particular machine can apply during a given period is Q, or the hours in the standard work period. If there are multiple machine of the same type on the farm, the maximum hours that a give type of machine can be used over a period is equal to $Q \times z_m$. It follows that in any given period, the maximum number of hours that any given machine can be used over a period will be less than or equal to $Q \times \max_m(z_m)$. One is added to this term so to make analysis possible for farms that do not use any equipment. Adding one to this term prevents division by zero problems. By multiplying this last term by 2000, this approximates the term to zero to the nearest 10^{-4}. This level of precision can be changed to suit the modeler's preference. This means for any feasible hourly allocation that a farmer can delegate in a given period, if the machine is not appropriate for carrying out $TASK(v,a)$ the acreage of $TASK(v,a)$ will be reduced by at most 10^{-4}.

Notice that the same idea applies to the hand labor terms. The denominator of these terms are also linear combinations of the binary feasibility terms of labor with respect to the considered task. There is a fundamental difference between the machine and labor terms since the supply of labor is perfectly inelastic. This means that the denominator must contain the hypothetical maximum number of labor hours that would be reasonably allocated into a given period for any task ($\frac{\max_{v,a(ACRE(v,a))}}{\left[min_{v,a(P(v,a))+1}\right]}$) to accommodate instance when hand labor is not appropriate for carrying out a $TASK(v,a)$. In this case the denominator of the term becomes $2000 \times \frac{\max_{v,a(ACRE(v,a))}}{\left[min_{v,a(P(v,a))+1}\right]}$. This gives rise to the transversality issues of the problem. Notice that for any given task, the maximum amount of hand labor hours will be less than or equal to the maximum number of starting acreage over the minimum productivity of hand labor for a given task. This term essentially represents the number of hours of hand labor that would be required to perform the most labor intensive job in a single period. By multiplying this value by 2000, this also reduces the acreage term to within 10^{-4} of zero when hand labor can not be used to carry out $TASK(v,a)$.

Recall that the $O(v,a)_t$ term specifies whether or not period (t) is within $TASK(v,a)$'s optimal time interval. If period (t) is within the optimal time interval, then the applied hours will reduce the $TASK(v,a)$ acreage for those machines and labor that are appropriate. If period (t) does not lie within the optimal time interval for $TASK(v,a)$ then no amount of hourly allocation will reduce the acreage of $TASK(v,a)$ in period (t). Since the delegation of hours increases the contemporaneous cost function, the model will not permit the delegation of hours towards the completion of $TASK(v,a)$ in periods that do not lie within the optimal time interval for the respective task.

$$g_t(\mathbf{a}_t, \mathbf{s}_t) = \begin{bmatrix} R(1)_t - \left[\sum_{m=1}^{M} \left[\frac{MH(1,m)_t}{MD(1,m)}\right] + \frac{UH(1)_t}{HD(1)}\right] \times O(1)_t \\ R(2)_t - \left[\sum_{m=1}^{M} \left[\frac{MH(2,m)_t}{MD(2,m)}\right] + \frac{UH(2)_t}{HD(2)}\right] \times O(2)_t \\ \vdots \\ R(v,a)_t - \left[\sum_{m=1}^{M} \left[\frac{MH(v,a,m)_t}{MD(v,a,m)}\right] + \frac{UH(v,a)_t}{HD(v,a)}\right] \times O(v,a)_t \\ \vdots \\ R(K)_t - \left[\sum_{m=1}^{M} \left[\frac{MH(K,m)_t}{MD(K,m)}\right] + \frac{UH(K)_t}{HD(K)}\right] \times O(K)_t \end{bmatrix} \tag{4.12}$$

$$st.\ MD(v,a,m) = [U(v,a,m] \times [E(v,a,m)] + [1 - U(v,a,m)] \times Q \times 2000 \times [\max_m(z_m) + 1]$$

$$HD(v,a) = F(v,a) \times P(v,a) + [1 - F(v,a)] \times 2000 \times \frac{\left[\max_{v,a(ACRE(v,a))}\right]}{\left[min_{v,a(P(v,a))+1}\right]}$$

The standard form of the dynamic optimization model is almost complete. Several additional constraints on the state and decision variables need to be addressed. First, since in the real world negative work hours do not exist, the $MH(v,a,m)_t$ and $UH(v,a)_t$ terms must all be non-negative across all time periods, tasks, and machines. Since we are also placing upper bounded constraints on the machine hours, we must constrain the $MH(v,a,m)_t$ terms from above. If two machines of the same type (m) were owned on the farm, then conceivably both could work at the same time. Therefore the upper constraint for periodic machine hours will be as follows.

$$MH(v,a,m)_t \leq z_m \times Q \ \forall v,a,m,t$$

As with time, negative area does not exist in the real world and hence all remainder acreage terms $R(v,a)_t$ must be non-negative. The remainder state variables must also conform to the transversality conditions. The initial acreage must be the exogenously determined acreage the farm plans for at the beginning of the growing season and all terminal acreage terms must equal zero signifying that all tasks have been completed by the end of the season. Hence using the standard notation of dynamic optimization problems the initial and terminal states must take on the following form.

$$\mathbf{s}_0 = \begin{bmatrix} ACRE(1) \\ ACRE(2) \\ \vdots \\ ACRE(v,a) \\ \vdots \\ ACRE(K) \end{bmatrix}, \quad \mathbf{s}_T = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

With all of the basic model attributes introduced, the functional form of the Lagrangian can be described. To avoid confusion, the form is written in the same way as the general form of the dynamic optimization Lagrangian and leaves out the terms relating to the constraints on the state and decision variables (Equation 4.13).

Because the problem has been put into the context of the generic problem, we can use the generic first order conditions to generate the conditions for the current problem. The first

$$\mathscr{L} = \sum_{t=0}^{T-1}\left[\sum_{(v,a)=1}^{K}\left[\sum_{m=1}^{M}[MH(v,a,m)_t \times (EC(v,a,m) + N(v,a,m) \times T(v,a,m) \times MW)] + UH(v,a)_t \times HW\right]\right]$$
$$-\sum_{t=1}^{T}\left[\sum_{(v,a)=1}^{K}\lambda_{(v,a),t} \times \left[\left[R(v,a)_{t-1} - \left[\sum_{m=1}^{M}\left[\frac{MH(v,a,m)_{t-1}}{MD(v,a,m)}\right] + \frac{UH(v,a)_{t-1}}{HD(v,a)}\right] \times O(v,a)_{t-1}\right] - R(v,a)_t\right]\right] \tag{4.13}$$

condition states that the additional costs from delegating a specific machine hour to a specific task in a specific period should equal the value of reducing the acreage of the task in the next period (Equation 4.14). The second condition says the same thing with respect to labor hours instead of machine hours (Equation 4.15). Both equations 4.14 and 4.15 make up the general first order conditions with respect to the decision variable. Notice that the acreage remainder term does not appear in the contemporaneous cost function. This means that the marginal cost will be the same regardless of acreage. This imposes constant returns to scale. The discounting term β, is assumed to be equal to one so that costs are weighted equally across periods. Essentially this means that the value of completing a particular task's acreage will be the same at any time period, this applies to all periods in which hours can allocated (Equation 4.16). Since it assumed that incomplete acres provide zero "scrap" value, there are zero cost savings in the T^{th} period (Equation 4.17).

$$\begin{array}{c} \frac{\partial \mathscr{L}}{\partial MH(v,a,m)_t} = D_{MH(v,a,m)_t} f_t(\mathbf{a}_t, \mathbf{s}_t) - \lambda_{(v,a),t+1} \times D_{MH(v,a,m)_t} g_t(\mathbf{a}_t, \mathbf{s}_t) = 0 \\ {[EC(v,a,m) + N(v,a,m) \times T(v,a,m) \times MW]} = \lambda_{(v,a),t+1} \times \frac{-O(v,a)_t}{MD(v,a,m)} \end{array} \quad t = 0, \cdots, T-1 \tag{4.14}$$

$$\begin{array}{c} \frac{\partial \mathscr{L}}{\partial UH(v,a)_t} = D_{UH(v,a)_t} f_t(\mathbf{a}_t, \mathbf{s}_t) - \lambda_{(v,a),t+1} \times D_{MH(v,a,m)_t} g_t(\mathbf{a}_t, \mathbf{s}_t) = 0 \\ UW = \lambda_{(v,a),t+1} \times \frac{-O(v,a)_t}{HD(v,a)} \end{array} \quad t = 0, \cdots, T-1 \tag{4.15}$$

$$\begin{array}{c} \frac{\partial \mathscr{L}}{\partial R(v,a)_t} = D_{R(v,a)_t} f_t(\mathbf{a}_t, \mathbf{s}_t) - \lambda_{(v,a),t+1} \times D_{R(v,a)_t} g_t(\mathbf{a}_t, \mathbf{s}_t) + \lambda_{(v,a),t} = 0 \\ \lambda_{(v,a),t} = \lambda_{(v,a),t+1} \end{array} \quad t = 1, \cdots, T-2 \tag{4.16}$$

$$\frac{\partial \mathscr{L}}{\partial R(v,a)_T} = D_{R(v,a)_T} v(\mathbf{s}_T) + \lambda_T = 0$$
$$\lambda_T = 0 \tag{4.17}$$

With respect to each of the first order conditions, notice that the left hand sides of equations 4.14 and 4.15 are both exogenous constants. Since these figures can not vary with the farmer's decision, it is probable that these equalities would not hold. Since this is the case, if the marginal cost of running a machine is greater than the marginal benefit of the reduction of acreage, these hours will go to zero. Since hours are constrained from the bottom by the number zero, if $[EC(v,a,m) + N(v,a,m) \times T(v,a,m) \times MW] > \lambda_{(v,a),t+1} \times \frac{-O(v,a)_t}{MD(v,a,m)}$ then the machine hours that will be delegated for that machine (m), $TASK(v,a)$, at time period (t) will be zero. Since the left hand side of this inequality is assumed to be positive, we can discuss why this might be the case. In the situation where there are no acres of $TASK(v,a)$ at period (t), this means that there is no gain from reducing the acres of $TASK(v,a)$ since the remaining acreage terms are constrained from below by zero as well. This would mean that the shadow value $\lambda_{(v,a),t+1}$ is zero implying that the marginal cost of allocating machine hours in period (t) would be greater than the benefit of reducing the acreage. Consider another situation where there are acres to complete but the machine (m) is not able to execute $TASK(v,a)$. By the way that we defined $MD(v,a,m)$ on the right hand side of the equality, if this is the case, then the right hand side will be approximately zero, forcing the model to delegate zero hours to $TASK(v,a)$ at any period. Another situation that would cause such an inequality is one in which period (t) is not within the optimal time interval for $TASK(v,a)$, forcing $-O(v,a)_t$ to be zero and therefore the right hand side of the relation would be zero resulting in the given inequality. The final instance of the given inequality is more complex since it could arise when there are acres to be completed within the optimal time interval in period (t) and the machine (m) may be able to execute the task. Recall that in any Lagrangian, the model specifies the λ values to solve the optimization problem. The way that the transition function and the transversality conditions are arranged dictate the values that the λ terms take in relation to the marginal costs of operating the machinery. These first order conditions are not complete in the strict sense. For each machine type, there is another term that links the tasks to one another by the machines that are able to complete them (Equation 4.18).

$$\sum_{(v,a)=1}^{K} MH(v,a,m)_t \leq z_m \times Q \ \ \forall m,t \tag{4.18}$$

4.4 Another Example: A Discrete Model Considering Multiple Machines

It may be helpful to see an extended, step-by-step example of such a problem that considers multiple machines and hand labor. For generality's sake, the machines, their needed labor and efficiency rates are arbitrarily assigned. Like any other model, exogenous variables need to be filled in order to solve for the optimal levels of the endogenous variables. These exogenous variables can be assigned by either the farmer or through more standardized values. It was stated earlier that standardized values could be off by as much as 50%. However, these values are still needed. Since the main use of the model is analyze the purchase of a machine that the farmer has not owned, direct values from the farmer may not be possible.

The first section of the model will be called the "Farmer's Form" which is the front-end form that the farmer will see and have to fill in. The farmer must provide the crops that he grows, each crop's respective acreage, and a description of all of the machines that the farmer currently uses. In this example, the crops that we are considering are sweet corn, tomatoes, asparagus, and apples. To keep the model simple, only three actions are considered: planting, pruning/tilling, and spraying for each crop. This corresponds to 12 tasks in total. Additional power unit inequality constants are needed for the model to incorporate the constraints. These constraints are added to keep the model from applying additional hours that a power unit can perform if it can work with several implements. That is, for every machine comprised of a power unit and an implement, the maximum number of machine hours that a given implement-power unit combination can not exceed $min(z_{power\ unit},\ z_{implement}) \times Q$. For all machines with a common power unit, the sum of their hours can not exceed $z_{power\ unit} \times Q$. To make it easier to present it is assumed that the farmer owns one tractor that runs every implement that he owns since multiple tractors will require more combinations of power unit and implement machines. This also requires further tables to match power units to implements. To make it easier to present in further tables, tasks and machines are indexed as they were in the previous sections(Table 4.3). The model considers seven different machines that the farmer can own. Notice that apples have zero acres to be planted. This is because they are an established tree perennial. This is an example of a task that is not applicable for a particular crop.

Table 4.3: Farmer's Form Example

		Action (a) Acreage		
	a	1	2	3
v	Crop	Tilling/Pruning	Planting	Spraying
1	Sweet Corn	5	5	5
2	Tomatoes	5	5	5
3	Asparagus	10	10	10
4	Apples	2	0	2

m	Machine	Number of Machines Owned (z_m)
1	Tiller/Pruner #1	1
2	Planter #1	0
3	Sprayer #1	1
4	Tiller/Pruner #2	1
5	Sprayer #2	1
6	Sprayer #3	1
7	Tiller/Pruner #3	1

The next section contains the remaining exogenous variables. These variables may be provided by the farmer when available for greater accuracy or be standardized values. This section includes the optimal periods for each task, the efficiency values of each of the machines and hand labor for each task, and the number of accompanying labor hours needed to operate a machine for an hour (Table 4.4[3]). Notice that in all of these tables $TASK(4,2)$, planting apples, has all zeros across the row. This is because the model assumes that this is not needed for established trees. It might also be confusing to see zeros in the efficiency terms since this could infer that it takes zero hours to perform an task over an acre which is of course not true. For simplicity's sake, whenever there is a zero efficiency value, the usefulness variable $U(v, a, m)$ is also zero. It is also important to know that each of the six periods are weeks and the Q term is 40 hours to represent a standard work week. This Q term can be variable and even subject to stochastic

[3]"HL" stands for hand labor.

shocks. The literature and case study respondents both mentioned that weather could limit the total workable field hours (Landers (2000) pp. 16-18). This is brought up in more detail in later sections but for now it is assumed that the farmer is able to perform fieldwork over the entire week.

Using the open source statistical software R[4], this scenario was programmed into a generic dynamic optimization model using the package lpsolve[5]. R was chosen since it is free to the public and has a moderately high level of computing power. The lpsolve package can accommodate up to a sum of 10,000 choice variables and state variables and 50,000 constraints (Buttrey (2005)). Modeling with problem under these terms, the model generates both graphics and a table with the ggplot package[6] (Figures 4.5, 4.6). This output plots the number of hours that each machine should be used in each period for each task. Since we've assumed that the supply of labor is perfectly elastic, it is also helpful to see if the labor allocation seems reasonable by plotting the labor usage in each period. Differentiating these labor hours by ones that are machine-assisted and those that are performed by hand draws attention to periods where a machine acquisition could aid in reducing hand labor hours.

In the initial simulation, hand labor hours peak in the third week when the model allocates 160 hand labor hours. This would mean that it would take as many as four full-time workers to complete the tasks in week three. Notice that the third week is optimal for planting both tomatoes and asparagus. Also of interest is the graph for Tiller/Pruner #2 which is designed for pruning an apple tree. This shows that there are no hours delegated to the machine over the season. This means that the added efficiency of adding the Tiller/Pruner (machine(4)) is not worth the cost of using it relative to hand labor and this is why you see a clump of hand labor hours allocated in the first period. This could mean that it is worth it to sell the pruner or rent it out to another farmer.

Using a loop function, the table that follows the initial simulation shows how key values change when a farmer iteratively adds an additional machines to his machine fleet. It is clear that the best implement to purchase is Planter #1. This is the case since it can be used for three

[4]http://www.R-project.org
[5]http://cran.r-project.org/web/packages/lpSolve/index.html
[6]http://cran.r-project.org/web/packages/ggplot2/index.html

different tasks that do not have any other mechanical alternatives (Table 4.4). The purchase of Planter #1 would enable the farmer to trade off approximately 128 hand labor hours in this peak period and reduce total machine and labor operating costs by approximately $1,125 each season. By purchasing the planter, the farmer is able to perform all of seasonal tasks with full-time worker (4.6). The purchase of any other machine yields no cost or hand labor savings. This is because the acreage profile does not exhaust the number of allocable hours for any of the other machines. Consider the case where the farmer can use one Sprayer #1 to spray all of his sweet corn and tomatoes within the optimal time periods. Adding another Sprayer #1 to the machine fleet does not assist the farmer since it will sit idle. In its present form, the model does not consider the fixed costs of machinery acquisitions the most obvious fixed cost being the machine's purchase price. These costs will be added on to the model after the simulations.

Table 4.4: Exogenous Values Example

	Efficiency ($\frac{hours}{acre}$)								Optimal Time (t)					
m / t	1	2	3	4	5	6	7	HL	1	2	3	4	5	6
$TASK(v, a)$														
(1,1)	$\frac{1}{2}$	0	0	0	0	0	$\frac{1}{4}$	8	1	1	0	0	0	0
(1,2)	0	$\frac{3}{4}$	0	0	0	0	0	10	0	0	0	1	0	0
(1,3)	0	0	1	0	0	0	0	14	0	0	0	0	0	1
(2,1)	$\frac{1}{2}$	0	0	0	0	0	$\frac{1}{4}$	8	1	0	0	0	0	0
(2,2)	0	$\frac{3}{4}$	0	0	0	0	0	10	0	0	1	0	0	0
(2,3)	0	0	1	0	0	0	0	14	0	0	0	0	1	1
(3,1)	$\frac{1}{2}$	0	0	0	0	0	0	9	1	1	0	0	0	0
(3,2)	0	$\frac{3}{4}$	0	0	0	0	0	11	0	0	1	1	0	0
(3,3)	0	0	0	0	1	0	0	15	0	0	0	0	1	0
(4,1)	0	0	0	2	0	0	0	12	1	0	0	0	0	0
(4,2)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
(4,3)	0	0	0	0	0	$\frac{6}{5}$	0	20	0	0	0	0	0	1

For v, 1=Sweet Corn, 2=Tomatoes, 3=Asparagus, 4=Apples. For a, 1=Tilling/Pruning, 2=Planting, 3=Spraying. For m, 1=Tiller/Pruner #1, 2=Planter #1, 3=Sprayer #1, 4=Tiller/Pruner #2, 5=Sprayer #2, 6=Sprayer #3, 7=Tiller/Pruner #3.

Table 4.5: Further Exogenous Values Example

	Labor Hours Required per Machine (m) Hour						
m	1	2	3	4	5	6	7
(v, a)							
(1,1)	1.2	0	0	0	0	0	1.1
(1,2)	0	1	0	0	0	0	0
(1,3)	0	0	3.3	0	0	0	0
(2,1)	1.2	0	0	0	0	0	1.1
(2,2)	0	1	0	0	0	0	0
(2,3)	0	0	3.3	0	0	0	0
(3,1)	1.2	0	0	0	0	0	0
(3,2)	0	1	0	0	0	0	0
(3,3)	0	0	0	0	1	0	0
(4,1)	0	0	0	2.2	0	0	0
(4,2)	0	0	0	0	0	0	0
(4,3)	0	0	0	0	0	2.6	0

(m)	Hourly Running Costs
1	\$118.00
2	\$135.00
3	\$199.50
4	\$158.00
5	\$190.00
6	\$189.00
7	\$166.50
HL	\$15.00

For v, 1=Sweet Corn, 2=Tomatoes, 3=Asparagus, 4=Apples. For a, 1=Tilling/Pruning, 2=Planting, 3=Spraying. For m, 1=Tiller/Pruner #1, 2=Planter #1, 3=Sprayer #1, 4=Tiller/Pruner #2, 5=Sprayer #2, 6=Sprayer #3, 7=Tiller/Pruner #3.

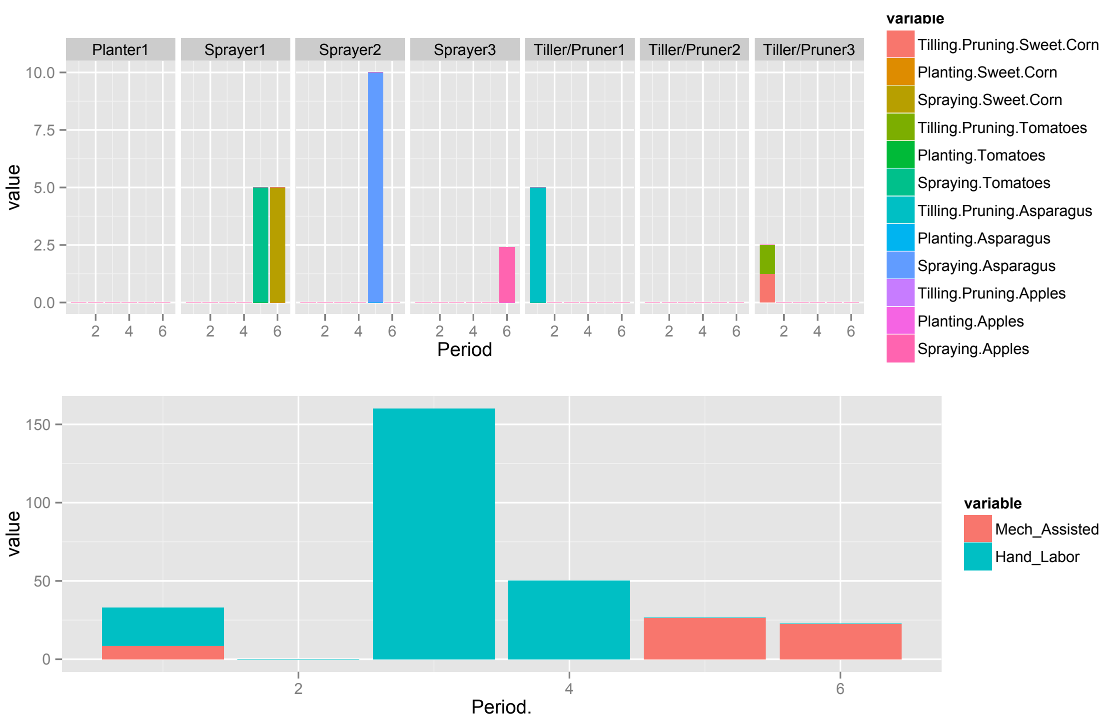

Figure 4.5: Graphical Initial Result Example

Table 4.6: Aquisition Scenario Table Example

		Purchase Machine (m)						
m	Original	1	2	3	4	5	6	7
Min. Production Cost	$8740.18	$8740.18	$7615.06	$8740.18	$8740.18	$8740.18	$8740.18	$8740.18
Difference from Original	$0.00	$0.00	$1125.12	$0.00	$0.00	$0.00	$0.00	$0.00
Max. Weekly Labor Hours	160	160	31.375	160	160	160	160	160
Difference from Original	0	0	128.625	0	0	0	0	0

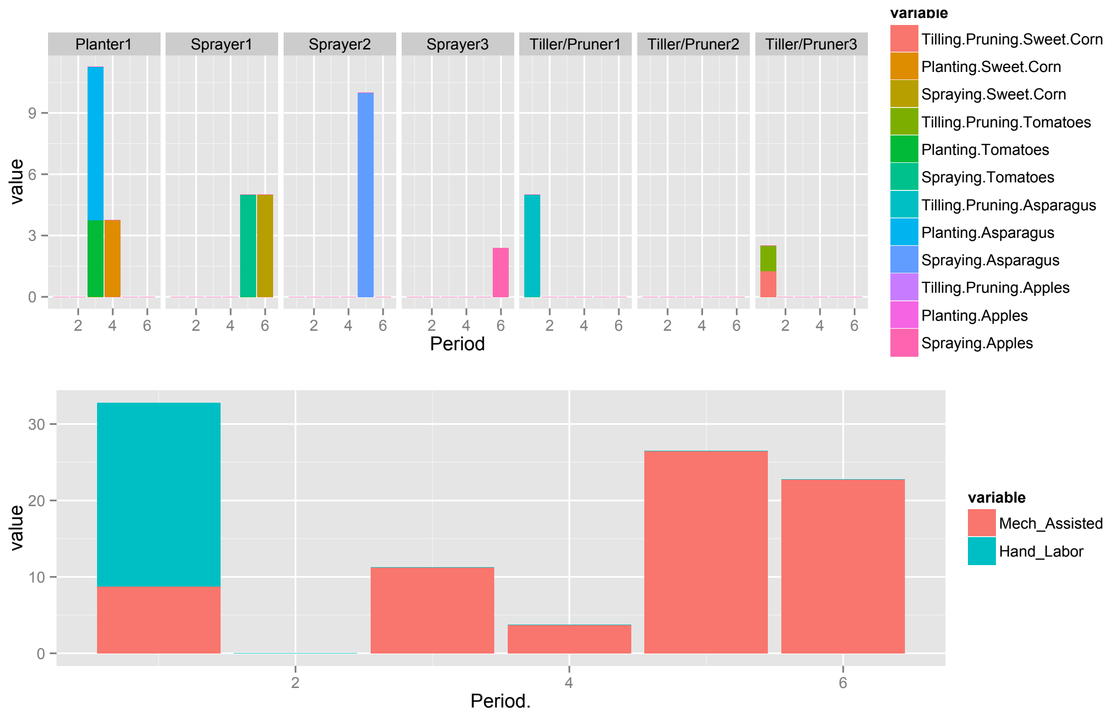

Figure 4.6: Result After Planter Acquisition Example

4.5 Comparative Statics: Expansion Simulations

4.5.0.9 Exogenous Variables

In addition to considering purchasing decisions, the model enables farmers to simulate expansions. Mentioned earlier, the term “expansion” is somewhat ambiguous. Scale expansions mean that the farmer increases total acreage and leaves the proportional composition of the crop mix the same. If the farmer grows on an acreage vector **a** then a 10% scale expansion would change the vector to $1.1 \times \mathbf{a}$. This requires changing a single term in the model to reflect this. Adding another crop to the current acreage or simply changing the composition of crop mix by increasing acreage of a particular crop is called a diversification expansion. This expansion can be modeled by changing the acreage of individual crops that the farmer grows. Finally, a farmer may also consider adding a high tunnel or a greenhouse to extend the season for particular crops. This is called a temporal expansion. From the testimony of Farmer #1, unheated high tunnels extended his season by approximately one month. Temporal expansions can be more difficult to model since larger equipment may not be able to work inside of high tunnels and it may change the efficiency terms of both machinery and labor. If these changes are incorporated in the model, simulations would be possible. Due to these complications, temporal expansions will not be modeled. Modeling with expansions also may enable farmers to consider sharing arrangements. It may be that two or more farmers could benefit by purchasing machinery jointly to service tasks between the farms. These tasks could be defined between the two farms and the optimal time intervals could be fitted to conform to the agreement between the farms. This would allow for feasibility tests for sharing arrangements and estimate the cost reductions to each farm. The remainder of the section is dedicated to performing simulations for expanding farms.

This section will present more realistic simulations than the previous examples. The primary goal of these simulations is to illustrate the machine and labor tradeoffs and dynamics when a farm expands production. These simulations will, to an extent, reenact the events of an expanding farm from the testimony of the case farms. Farms will be quite small, on the order of one and a half acres. Since the goal is to simulate labor tradeoffs, care must be taken when establishing the tasks, time periods, and equipment the model will consider. Stated earlier, the model is limited to only 10,000 choice variables. Implying the following restriction on possible combinations.

$$[[Machines + 1] \times Crops \times Time\ Periods] + [Crops \times Tasks \times [Time\ Periods + 1]] \leq \textit{10,000}$$

Because these simulations are primarily concerned with labor-machinery dynamics, crop tasks must have both machine and labor alternatives to show the impact that expansion will have on the viability of machinery acquisitions. The model will consider tilling, transplanting/planting, weed management, and spraying tasks. Since many crops lack economical mechanical harvesting alternatives on small-scale farms, harvesting will not be considered in the model. The simulation farm will grow both warm and cool season crops to show how different diversification expansions would impact a farm. A warm crop acreage expansion for a farm that primarily grows warm crops is different from a cool crop expansion since the timing differs between crop tasks. Machines must be reasonable alternatives to hand labor for the tasks on the farm as well as ones that are typical adoptions for small to medium-scale fruit and vegetable farms (Table 4.7).

Table 4.7: Simulation Tasks and Machines

v	Crop	a	Action
1	Sweet Corn	1	Tilling
2	Tomatoes	2	Planting/Transplanting
3	Peppers	3	Weed Managment
4	Broccoli	4	Spraying
5	Head Lettuce		

m	Machine
1	40 hp. Tractor with 4 ft. Rototiller
2	40 hp. Tractor with 4 ft. Disk Harrow
3	40 hp. Tractor with 15 ft. Corn planter
4	40 hp. Tractor with Two Person Transplanter
5	40 hp. Tractor with Mulch Layer
6	40 hp. Tractor with 15 ft. Rotary Hoe
7	40 hp. Tractor with 80 ft. Pull-Type Sprayer
8	8 hp. Walk Behind Tiller

It is assumed that the farmer uses a four-foot plastic mulch system on all of these crops but corn. Figure 2 shows a four-foot bed system that was used as the basis for the model simulations. There are 18-inch tracks for the tractor and implement tires between the four-foot beds and the farm uses the row spacing guidelines recommended by the 2013 Midwest Vegetable Production Guide for Commercial Growers (MVPGCG (2013)) (Figure 4.7).

The machine efficiency values were difficult to collect since literature is scarce. However, efficiency rates may be estimated with given implement widths and assumed speeds. Using

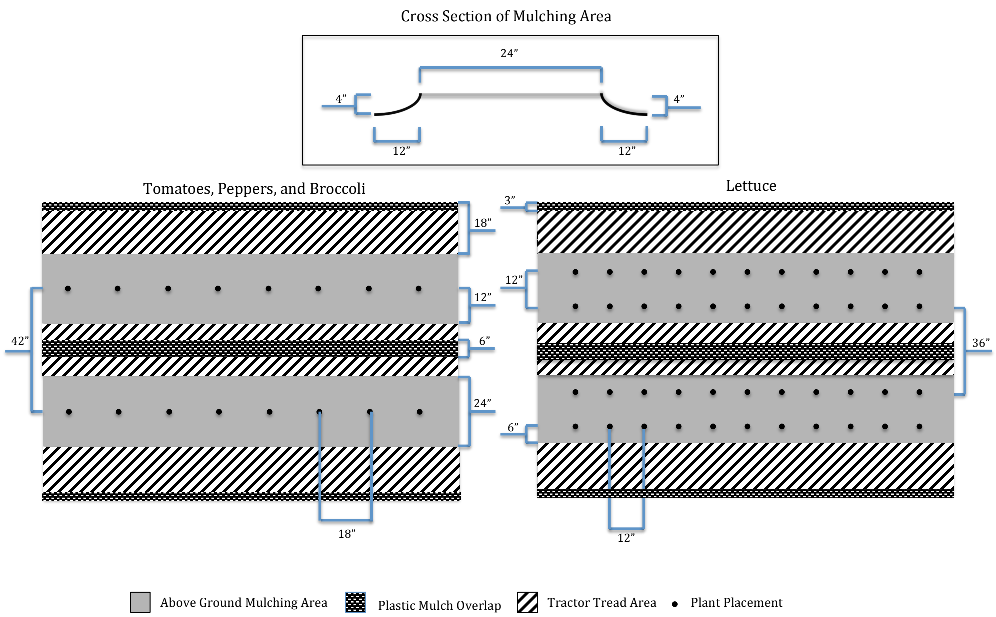

Figure 4.7: Four-Foot Bed Spacing

demonstration footage, the speeds can be found and the spot efficiency rate can be calculated by using $\frac{miles}{hour} \times \frac{5{,}280\ ft.}{1\ mile} \times width\ (ft.) \times \frac{1\ acre}{43{,}560\ ft.^2} = \frac{acres}{hour}$. Spot work rates are the machine's rate of efficiency if it is continuously working without making turns or stopping. The overall work rate of a machine applies an efficiency rate to the spot work rate to take into account turning and stops where $overall\ work\ rate = [spot\ work\ rate] \times [efficiency\ rate]$. Without using a farmer's actual data these efficiency rates are difficult to calculate. The shape of the field, the power unit's fuel capacity and the seed and tank capacities of seeders, transplanters, and sprayers will impact the efficiency rate (Landers (2000), pp. 24-33). Since efficiency rates require field experiments, a modest efficiency rate of 60% will be used in the model for all pieces of equipment (Table 4.8). As before, labor is assumed to interact with the machine 120% of the running time to account for breakdowns, refueling and switching implements. The assumed tractor model is the Kubota L3940 with 8 FST shuttle gears. TractorData.com provides transmission data including the speed the tractor travels at different gears (TractorData (2011)). Speeds will be matched to the gear speeds. Because each pass of the tractor will create at least one new tractor tread, 1.5 feet will be added to machines widths less than seven feet except for the walk-behind rototiller.

Table 4.8: Machinery Overall Work Rates

m	Miles per Hour	Width (ft.)	Efficiency Rate	Overall Work Rate $\left(\frac{acres}{hour}\right)$
1	0.90	4.00	60%	0.36
2	4.70	4.00	60%	1.88
3	6.60	18.00	60%	8.64
4	1.30	4.00	60%	0.52
5	0.90	4.00	60%	0.36
6	6.60	15.00	60%	7.20
7	3.20	80.00	60%	18.62
8	0.80	1.67	60%	0.09

For m, 1=4 ft. Rototiller, 2= Disk, 3=Corn planter, 4=Transplanter, 5=Mulch Layer, 6= Rotary Hoe, 7= Sprayer, 8=Walk Behind Tiller.

Hand labor was calculated in a similar way. All laborers are assumed to have one jab planter, a one row Jang planter, one backpack sprayer, and one stirrup hoe to complete these tasks. Hand transplanting efficiency rates were calculated by examining demonstration footage of a one-handed jab transplanter. The footage showed that a single worker could perform 32 transplants in about 3 minutes and six seconds. Assuming 200-foot long rows, the number of transplants in each 200-foot row was calculated for each row. Adding in one of the tread widths, the overall work rate for a hand transplanter is $\frac{5.5\ ft. \times 200\ ft.}{row} \times \frac{1\ acre}{43{,}560\ ft.^2} \times \frac{rows}{plant} \times \frac{32\ plants}{3.2\ min.} \times \frac{60\ min.}{1\ hr.} \times 60\%$. A Sustainable Agriculture Research and Education (SARE) study calculated the overall work rate of weeding with a stirrup hoe to be about 0.061 acres per hour this rate will be used for the simulations (Gallandt (2010)). A backpack sprayer is assumed to have a spray distance of four feet. We will assume that a worker walks in one of the wheel treads. Adding an 18-inch wheel tread to the four-foot row yields the workable width of a hand worker. Since tilling by hand is quite labor intensive and not often used, it is assumed that there are no hand labor alternatives to tilling (Table 4.9). With the help of Linda Naeve, an Iowa State University Extension specialist in the Value Added Agriculture Program, we estimate laying a 100-foot row of plastic mulch by hand takes between 60 and 70 worker minutes; 65 minutes of labor hours will be assumed. Assuming 100 foot rows, there will be approximately 79 plastic beds to lay in one acre $\left(\frac{43{,}560\ ft.^2}{acre} = [1.5\ ft. + 4\ ft.] \times 100\ ft. \times rows \Rightarrow \cong 79\ rows\right)$. Assuming that it takes 65 minutes per row, then it takes about of 85 hand labor hours to lay an acre of mulch by hand.

With these efficiency values in place, we can link machines and labor to their appropriate tasks. From Farmer #1's testimony, field corn implements can be used for sweet corn tasks but are not appropriate for any of the other crops in the set we are considering (Table 4.10).

Table 4.9: Hand Labor Overall Work Rates

v,a	Miles per Hour (Plants/Min.)	Width (ft.)	Efficiency Rate	Overall Work Rate $\left(\frac{acres}{hour}\right)$
1,1	–	–	–	–
1,2	3.00	0.67	60%	0.15
1,3	–	–	–	0.06
1,4	1.00	3.50	60%	0.25
2,1	–	–	–	–
2,2	(10.32)	3.50	60%	0.04
2,3	–	–	–	0.01
2,4	1.00	3.50	60%	0.25
3,1	–	–	–	–
3,2	(10.32)	3.50	60%	0.04
3,3	–	–	–	0.01
3,4	1.00	3.50	60%	0.25
4,1	–	–	–	–
4,2	(10.32)	3.50	60%	0.04
4,3	–	–	–	0.01
4,4	1.00	3.50	60%	0.25
5,1	–	–	–	–
5,2	(10.32)	3.50	60%	0.03
5,3	–	–	–	0.01
5,4	1.00	3.50	60%	0.25

For v, 1=Sweet Corn, 2=Tomatoes, 3=Peppers, 4=Broccoli, 5=Lettuce. For a, 1=Tilling, 2=Planting, 3=Weed Management, 4=Spraying.

We can now move on to the standardized costs for using machinery and labor. These costs are divided into the power unit's portion of the costs and the implement's portion of the cost. These power unit costs were calculated using Iowa State's 'Machine Cost Calculator' by inserting the efficiency rate and horsepower. A 40 horsepower, four-wheel drive tractor is used in the simulations. Inflation adjusted implement costs from UC Davis's Cost Return Studies provides the implement costs. The walk behind rototiller was more difficult to find. Using the manual for a Honda GX240 engine, the fuel efficiency was calculated to be 0.92 gallons per operating hour. The price of fuel was assumed to be \$3.56, the average price of fuel on March 11th, 2013 after

Table 4.10: Machine and Labor Usefulness Matrix

		U.v.a.								F.v.a.
v,a	i	1	2	3	4	5	6	7	8	HL
1,1		1	1	0	0	0	0	0	1	0
1,2		0	0	1	0	0	0	0	0	1
1,3		0	0	0	0	0	1	1	0	1
1,4		0	0	0	0	0	0	1	0	1
2,1		1	0	0	0	0	0	0	1	0
2,2		0	0	0	1	0	0	0	0	1
2,3		0	0	0	0	1	0	0	0	1
2,4		0	0	0	0	0	0	1	0	1
3,1		1	0	0	0	0	0	0	1	0
3,2		0	0	0	1	0	0	0	0	1
3,3		0	0	0	0	1	0	0	0	1
3,4		0	0	0	0	0	0	1	0	1
4,1		1	0	0	0	0	0	0	1	0
4,2		0	0	0	1	0	0	0	0	1
4,3		0	0	0	0	1	0	0	0	1
4,4		0	0	0	0	0	0	1	0	1
5,1		1	0	0	0	0	0	0	1	0
5,2		0	0	0	1	0	0	0	0	1
5,3		0	0	0	0	1	0	0	0	1
5,4		0	0	0	0	0	0	1	0	1

For v, 1=Sweet Corn, 2=Tomatoes, 3=Peppers, 4=Broccoli, 5=Lettuce. For a, 1=Tilling, 2=Planting, 3=Weed Management, 4=Spraying. For m, 1=4 ft. Rototiller, 2= Disk, 3=Corn planter, 4=Transplanter, 5=Mulch Layer, 6= Rotary Hoe, 7= Sprayer, 8=Walk Behind Tiller.

removing a 12% excise tax to reflect the off-road price of fuel. The hourly wages for mechanized and hand laborers were found using the Bureau of Labor Statistics most current median hourly wages for agricultural equipment operators and farm workers for Iowa respectively (Table 4.11).

Fixed costs need to be accounted for as well. These are useful for generating break-even analysis for purchasing machinery. Makes, models, the year of manufacture, the location of sale, and the number of hours of operation impact the posted prices of machinery. For the purposes of the simulation, we have to assume that the farmer has a small list of for-sale postings. These prices were collected on May 11th, 2013 from TractorHouse.com and Honda's website (Table 4.12).

Finally, the timing of the tasks needs to be established. Iowa State's Extension provides planting and growing periods for each of these crops (Jauron (2013)). GardenAction has the

Table 4.11: Machine and Labor Hourly Cost Table

m	$\frac{Power\ Unit\ Cost}{Hour}$	$\frac{Implement\ Cost}{Hour}$	$\frac{Total\ Cost}{Hour}$	Hand Labor Wage	Mechanized Labor Wage
1	$9.04	$1.36	$10.40	$11.12	$14.57
2	$7.16	$0.32	$7.48		
3	$9.07	$2.76	$11.83		
4	$9.04	$4.41	$13.45		
5	$9.04	$0.18	$9.22		
6	$9.07	$2.17	$11.24		
7	$9.12	$1.35	$10.47		
8	$3.14	$0.00	$3.14		

For m, 1=4 ft. Rototiller, 2= Disk, 3=Corn planter, 4=Transplanter, 5=Mulch Layer, 6= Rotary Hoe, 7= Sprayer, 8=Walk Behind Tiller.

Table 4.12: Machinery Makes, Models, and Posted Prices

m	Make	Model	Year	Operating Hours	Location	Posted Price
Tractor	Kubota	L3940HST	2009	1,000	Colo, IA	$21,500
1	Muratori	MZ9XL	2011	0	Decorah, IA	$6,600
2	Land Pride	DH1048	2012	0	Macedonia, IA	$800
3	Kinze	2000	2000	–	Elkander, IA	$17,500
4	Checchi & Maggli	WOLF	2010	0	Decorah, IA	$5,995
5	Checchi & Maggli	AL	2011	0	Decorah, IA	$5,400
6	Yetter	3415	2004	–	Athens, MI	$3,300
7	Fast	7410	1999	–	Estherville, IA	$16,500
8	Honda	FRC800	2012	0	Des Moines, IA	$2,699

For m, 1=4 ft. Rototiller, 2= Disk, 3=Corn planter, 4=Transplanter, 5=Mulch Layer, 6= Rotary Hoe, 7= Sprayer, 8=Walk Behind Tiller.

timing for soil preparation. For mulched crops, the mulching period takes place between the soil prep period and the planting period. With the exception of a single herbicide spraying for corn, all other spraying tasks are assumed to be fungicide applications. Pioneer's researchers specifies that optimal fungicide application should take place between the VT and R2 plant stages which occurring in approximately the final two weeks of July according to University Wisconsin's extension (Lauer (1997)), (Jeschke (2010)). The fungicide applications for the remaining crops were found through Purdue's extension and the 2013 Midwest Vegetable Guide for Commercial Growers (Egel (2013a); Rhodes (2003); Egel (2013b); MVPGCG (2013)). A calendar was set up consisting of 20 weeks. This is the minimum number of weeks needed to incorporate all the tasks in the simulation (Table 4.13).

Table 4.13: Optimal Time Matrix

		March				April				May				June				July			
v,a	t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1,1		0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2		0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0
1,3		0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1,4		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
2,1		0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
2,2		0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
2,3		0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
2,4		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0
3,1		0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
3,2		0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
3,3		0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
3,4		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
4,1		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4,2		0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
4,3		0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4,4		0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
5,1		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5,2		0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5,3		0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5,4		0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0

For v, 1=Sweet Corn, 2=Tomatoes, 3=Peppers, 4=Broccoli, 5=Lettuce. For a, 1=Tilling, 2=Planting, 3=Weed Management, 4=Spraying.

4.5.0.10 Scale Expansions

To start out the scenarios, the simulation farm will grow on two acres producing two warm season and two cool season crops: tomatoes, peppers, broccoli, and head lettuce and have only a walk behind rototiller as a power unit (Table 4.14). The farmer grows a half-acre of each crop. This is a similar situation that Farmer #2 started with when he first began producing on two rented acres. Three out of the four crops considered here were main crops grown by Farmer #4 and at this level of production he only had a walk-behind tiller. Although labor can be added infinitely, the hourly allocation of labor throughout the year will be more realistic if we use a reasonable constraint. The labor hours may not be spread out as evenly over the season if the farm does not have a fixed number of workers. This simulation will assume the farm's workforce consists of two workers. Provided that the simulation is a success, we will stay with two workers for the remainder of the simulations unless otherwise stated.

Table 4.14: Machine and Acreage Before a Scale Expansion

m	Use	v	Acres
1	0	1	0
2	0	2	0.5
3	0	3	0.5
4	0	4	0.5
5	0	5	0.5
6	0		
7	0		
8	1		

For m, 1=4 ft. Rototiller, 2= Disk, 3=Corn planter, 4=Transplanter, 5=Mulch Layer, 6= Rotary Hoe, 7= Sprayer, 8=Walk Behind Tiller. For v, 1=Sweet Corn, 2=Tomatoes, 3=Peppers, 4=Broccoli, 5=Lettuce.

Under this simulation, labor hours peak in the 3rd week of March with most of them going to laying mulch by hand. The 2nd week in May is also a busy period mostly due to mulch laying for the warm season crops. Working with a walk-behind rototiller, tilling for each crop takes approximately 5.5 hours (4.8). The figure below is the result of the simulation for this farm at this level of production. The first pane shows the machine profile chart for each machine that the model considers, a 40 horsepower tractor with a transplanter, a four-foot disk harrow, a four foot tiller, a corn planter, a mulch layer, a rotary hoe, and a sprayer, and a walk behind tiller. These show how many hours each machine is being used, the tasks that they are being used for, and the time in which the machine is being used. The hours are shown on the y-axis, the time period is on the x-axis, and the task is denoted by the color code to the right of the profile charts.

Notice that since the farm does not have a 40 horsepower tractor or any of the implements that go with it, the farmer cannot allocate hours with these machines. The only machine that the farmer owns at this point is a walk-behind rototiller. The simulation allocates walking tiller hours to the 3rd week and the 10th week of the season to till for tomatoes, peppers, broccoli, and lettuce.

The second pane in the figure shows the labor profile chart for the farm. This shows how many labor hours are being allocated in each week to complete the task of the farm and breaks labor hours down by mechanically assisted labor and hand labor. Hours are displayed on the y-axis and time periods are displayed on the x-axis. Hand labor hours are shown in green and mechanically assisted labor hours are shown in red.

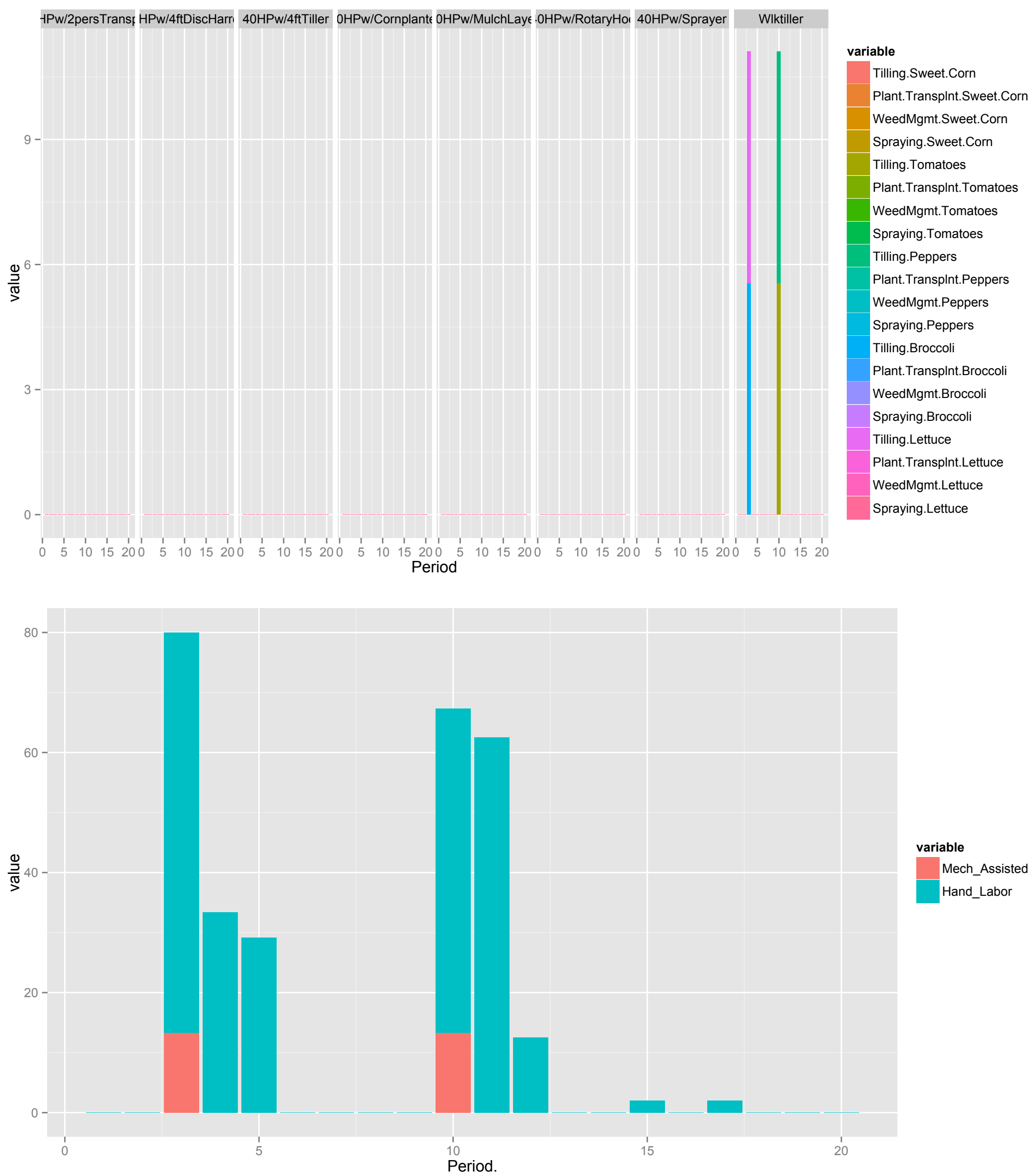

Figure 4.8: Machine and Labor Profile Before Scale Expansion

Table 4.15 is an acquisition table that presents comparative statics on machinery acquisition for the current farm growing on two acres with a walk-behind rototiller. This table provides a summary of cost savings that a purchase of a given machine would yield. To show the degree that a machine acquisition would impact acute farm work, this table also shows the difference between the maximum labor hours allocated before and after the machine acquisition. A machine purchase that reduces labor hours in the busiest weeks may be more helpful to a farmer than other machines, including ones that yield higher cost reductions. The last two rows shows the purchase price of each implement, found in May 2013. By dividing these prices by the operating cost savings yields the number of seasons it would take for a farm to pay off the purchase costs from cost savings alone.

At this level, acquiring a mulch layer would produce the highest cost savings, reducing operating costs for these tasks by nearly $2,000. The mulch layer would also alleviate the hourly allocation in the third week (Table 4.15). However, any of these other implements would also require a tractor implying additional costs. Farmer #2's first purchases were a tractor, a mower, and a disk. These purchases were primarily made to help incorporate organic matter into the soil for fertilization, a task not considered in the model. However, a mulch layer was on his "wish" list.

Farmer #2

"... at this point I just roll it up by hand on various sides and its ready to go and we've a decent system figured out for it but for $1200 I can buy a machine that will lay down drip tape underneath it and do a nice job laying down plastic and that's a nice machine. That's towards the top of the wish list at this point. Then in a couple of years I hope to one of those."

We will now continue by carrying out the first expansion. This will be a 250% scale expansion. This again mimics the expansion of Farmer #2 where he expanded from 2 to 5 acres but continued to produce roughly the same crops. From Farmer #2's testimony, he had acquired a tractor, a pull-type rototiller, and a disk prior to his expansion. To further replicate his expansion, we will assume that, like Farmer #5, the farmer in the model purchased a disk and a 40 horsepower tractor, and a four-foot rototiller. As with any scale expansion, we will assume that proportional composition of the crops grown will stay the same (Table 4.16).

Table 4.15: Acquisition Table Before a Scale Expansion

Machine Purchase	Original	4 ft. Rototiller	4 ft. Disk Harrow	15 ft. Corn Planter	Transplanter	Mulch Layer	15 ft. Rotary Hoe	80 ft. Pull-Type Sprayer
	Original Used	0	0	0	0	0	0	0
Optimized Cost	$3,345.67	$3,050.32	$3,345.67	$3,345.67	$2,982.20	$1,347.46	$3,345.67	$3,259.19
Difference from Original	$0.00	-$295.35	$0.00	$0.00	-$363.47	-$1,998.21	$0.00	-$86.48
Max. Weekly Labor Allocation	80 hours	80 hours	80 hours	80 hours	80 hours	29 hours	80 hours	80 hours
Difference from Original	0 hours	0 hours	0 hours	0 hours	0 hours	-51 hours	0 hours	0 hours
Purchase Price	–	$6,600	$800	$17,500	$5,995	$5,400	$3,300	$16,500
Seasons to Recoup Purchase	–	23	–	–	16	3	–	191

Table 4.16: Machine Fleet and Crop Acreage After a 250 Percent Scale Expansion

m	Use	v	Acres
1	1	1	0
2	1	2	1.25
3	0	3	1.25
4	0	4	1.25
5	0	5	1.25
6	0		
7	0		
8	1		

For m, 1=4 ft. Rototiller, 2= Disk, 3=Corn planter, 4=Transplanter, 5=Mulch Layer, 6= Rotary Hoe, 7= Sprayer, 8=Walk Behind Tiller. For v, 1=Sweet Corn, 2=Tomatoes, 3=Peppers, 4=Broccoli, 5=Lettuce.

As expected, labor requirements increased significantly after this expansion (Figure 4.9). So much so that two additional workers needed to be "hired" in order to complete these tasks. This follows what Farmer #2 did shortly after he expanded from two to five acres. However, Farmer #2 hired only two part-time workers. This could be due to the fact that labor and machine efficiency were modestly estimated with a 60% efficiency rate and labor hours and periods are confined to a 40 hour work week. According to the simulation, a mulch layer at this level of production would offer even more cost reductions and required labor hours significantly. With the purchase of mulch layer, operating costs would be reduced by 66% it would also enable two workers to perform the farm activities instead of four suggesting that a mulch layer may help offset hiring additional workers for Farmer #2. A transplanter purchase would also yield a sizable reduction in operating costs (Table 4.17). Farmer #2 was not interested in purchasing a transplanter because the CSA he worked with in the past determined it was not as productive as three workers working by hand.

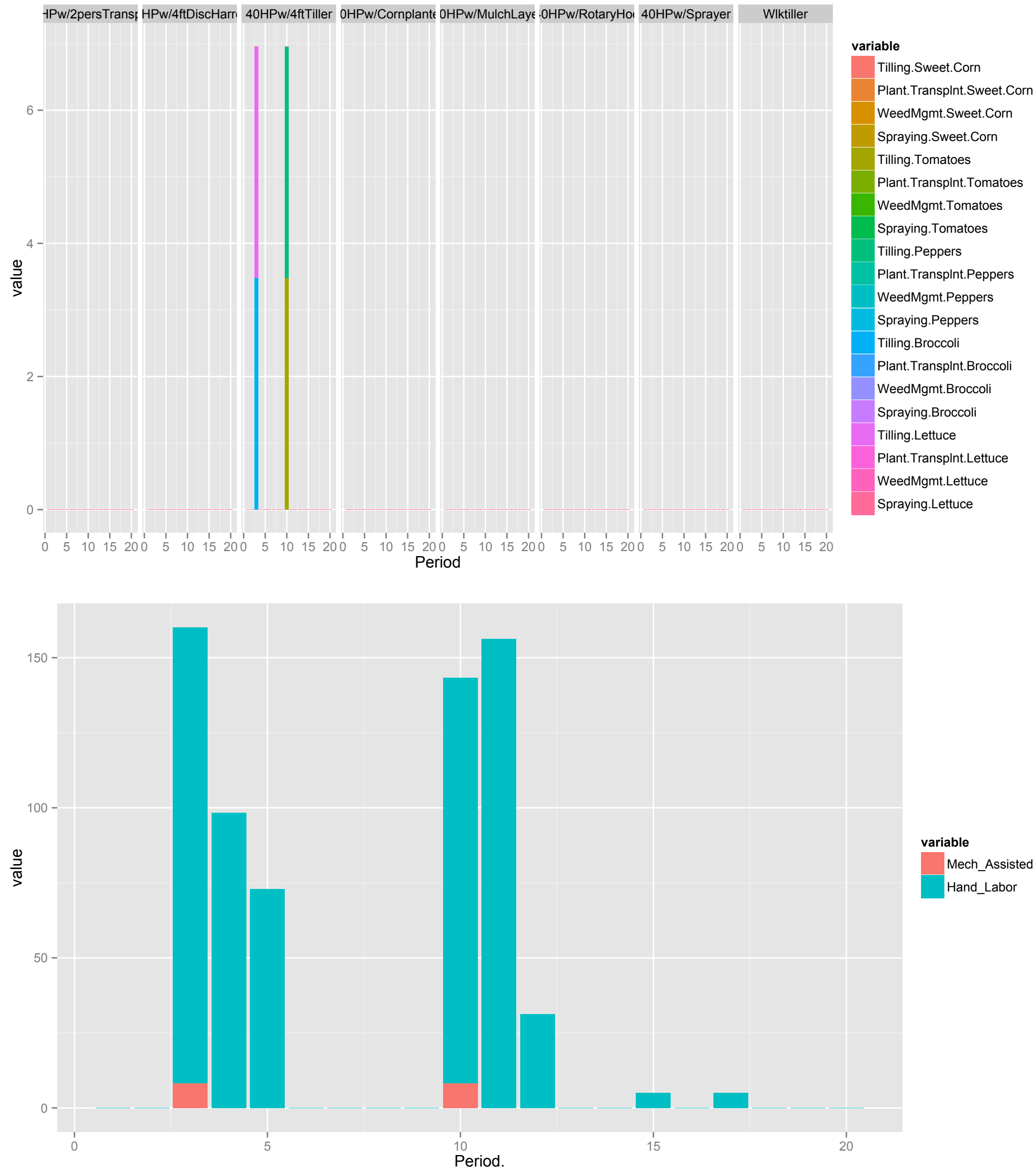

Figure 4.9: Machine and Labor Profile After a 250 Percent Scale Expansion

4.5.0.11 Diversification Expansion

The next simulation will mimic the second expansion of Farmer #5 where he went from 6.5 acres to 21.5 acres but with a disproportionate increase in sweet corn. Before the expansion, the farmer worked full-time by himself with some assistance from his son. Like Farmer #5, the farmer in the simulation has one tractor, one tiller, a transplanter, a walk-behind rototiller, a

Table 4.17: Acquisition Table After a 250 Percent Scale Expansion

Machine Purchase	Original	4 ft. Rototiller	4 ft. Disk Harrow	15 ft. Corn Planter	Transplanter	Mulch Layer	15 ft. Rotary Hoe	80 ft. Pull-Type Sprayer
	Original Used	1	1	0	0	0	0	0
Optimized Cost	$7,625.82	$7,625.82	$7,625.82	$7,625.82	$6,717.13	$2,630.30	$7,625.82	$7,409.60
Difference from Original	$0.00	$0.00	$0.00	$0.00	-$908.69	-$4,995.52	$0.00	-$216.22
Max. Weekly Labor Allocation	160 hours	160 hours	160 hours	160 hours	160 hours	73 hours	160 hours	160 hours
Difference from Original	0 hours	0 hours	0 hours	0 hours	0 hours	-87 hours	0 hours	0 hours
Purchase Price	–	$6,600	$800	$17,500	$5,995	$5,400	$3,300	$16,500
Seasons to Recoup Purchase	–	–	–	–	7	2	–	77

mulch layer, a disk harrow, and a rotary hoe to stand in for his cultivator. Before the expansion, Farmer #5 stated that he grew about 2.5 acres of sweet corn at this level of production. The remainder of the farm's acreage is evenly distributed over the rest of the crops (Table 4.18).

Table 4.18: Machine Fleet and Crop Acreage Before a Diversification Expansion

m	Use	v	Acres
1	1	1	2.50
2	1	2	1.00
3	0	3	1.00
4	1	4	1.00
5	1	5	1.00
6	1		
7	0		
8	1		

For m, 1=4 ft. Rototiller, 2= Disk, 3=Corn planter, 4=Transplanter, 5=Mulch Layer, 6= Rotary Hoe, 7= Sprayer, 8=Walk Behind Tiller. For v, 1=Sweet Corn, 2=Tomatoes, 3=Peppers, 4=Broccoli, 5=Lettuce.

The resulting machine profile for this level of production demonstrates the labor reducing potential of machinery when you compare it to the previous labor profile. A farmer working approximately half time would be able to perform all of the considered tasks with a well-equipped machine fleet (Figure 4.10)), although a part time worker would be very busy over the middle weeks in May (Figure 4.11). This is significant because before this level of production, Farmer #5 had a full time off- farm job. If a farmer had any activities such as marketing during these periods, the farmer could not maintain production while working half time. During the first season that Farmer #5 had this level of acreage, he quit his full time off-farm job. In this level of production, a sprayer or a corn planter would offer modest cost reductions and both would reduce the peak hours in the labor profile (Table 4.19).

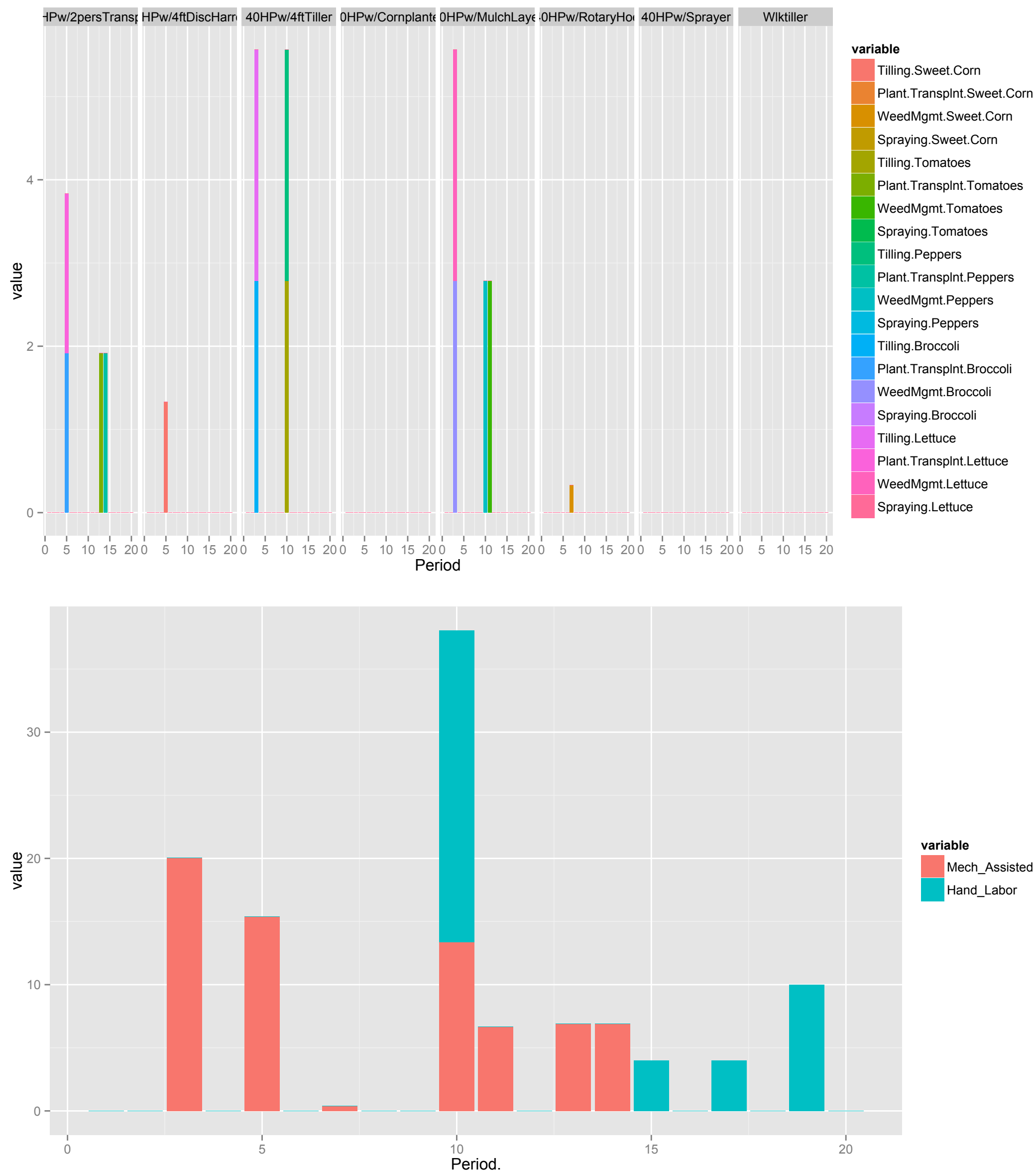

Figure 4.10: Machine and Labor Profile Before a Diversification Expansion

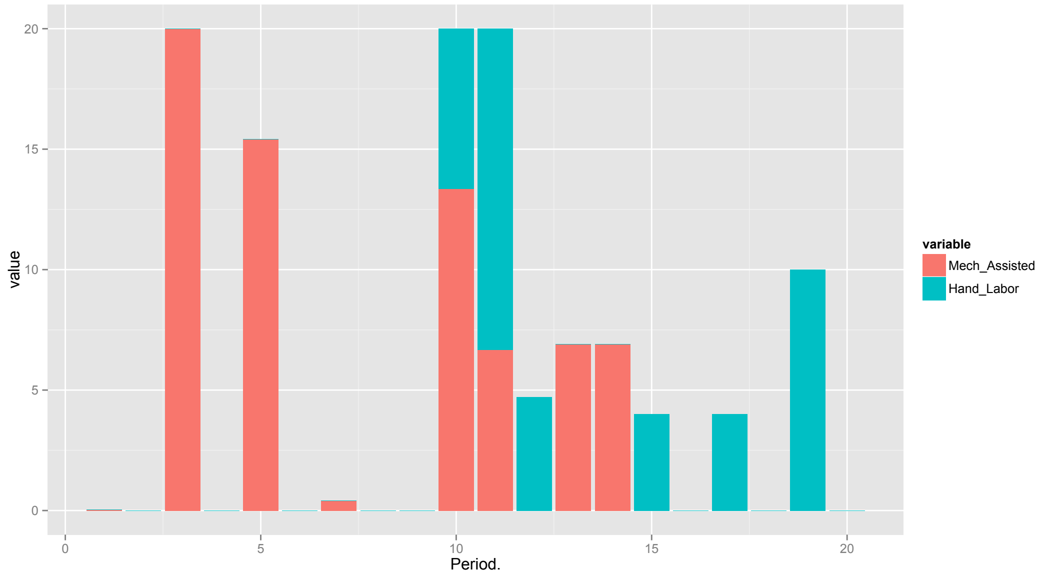

Figure 4.11: Labor Profile Before a Diversification for a Half-time Farmer

In Farmer #5's expansion from 6.5 to 21.5 acres, sweet corn acreage increased from 2.5 acres to 10 acres. This expansion will follow this convention with the remainder expansion acreage split evenly over the rest of the crops. Notice that it increases sweet corn's proportion of the crop mix. Farmer #5 has not purchased any more machinery since the expansion due to the high cost of land. We will assume that the farmer in the simulation has the same machine fleet as he had before the expansion (Table 4.20).

Table 4.19: Acquisition Table Before a Diversification Expansion

Machine Purchase	Original	4 ft. Rototiller	4 ft. Disk Harrow	15 ft. Corn Planter	Transplanter	Mulch Layer	15 ft. Rotary Hoe	80 ft. Pull-Type Sprayer
	Original Used	1	1	0	1	1	1	0
Optimized Cost	$1,713.34	$1,713.34	$1,713.34	$1,427.61	$1,713.34	$1,713.34	$1,713.34	$1,432.25
Difference from Original	$0.00	$0.00	$0.00	-$177.30	$0.00	$0.00	$0.00	-$281.09
Max. Weekly Labor Allocation	38 hours	38 hours	38 hours	22 hours	38 hours	38 hours	38 hours	30 hours
Difference from Original	0 hours	0 hours	0 hours	-15 hours	0 hours	0 hours	0 hours	0 hours
Purchase Price	–	$6,600	$800	$17,500	$5,995	$5,400	$3,300	$16,500
Seasons to Recoup Purchase	–	–	–	99	–	–	–	59

Table 4.20: Machine Fleet and Crop Acreage After a Sweet Corn-Skewed Diversification Expansion

m	Use	v	Acres
1	1	1	10.00
2	1	2	2.88
3	0	3	2.88
4	1	4	2.88
5	1	5	2.88
6	1		
7	0		
8	1		

For m, 1=4 ft. Rototiller, 2= Disk, 3=Corn planter, 4=Transplanter, 5=Mulch Layer, 6= Rotary Hoe, 7= Sprayer, 8=Walk Behind Tiller. For v, 1=Sweet Corn, 2=Tomatoes, 3=Peppers, 4=Broccoli, 5=Lettuce.

After this expansion, the hourly distribution is spread out more over the season. This is because the model has binding hourly constraints in certain periods so it is forced to push more hours in other optimal periods. In the simulation, planting corn by hand is the task that accounts for the most hand labor hours. Hand planting corn would span four weeks with one week entirely devoted to planting (Figure 4.12). With a single worker, this is a very busy schedule. In his expansion, Farmer #5 was able to maintain this level of production with mostly his full-time labor and some help from his son for two seasons before he hired an additional worker. Because the land was expensive, Farmer #5 was not able to make any machine purchases since he expanded in 2009 but is now considering purchasing a 70 horsepower tractor, a field conditioner, and a 20-foot cultivator to help with his sweet corn crop. The acquisition table suggests that a corn planter would offer the greatest cost savings (Table 4.21).

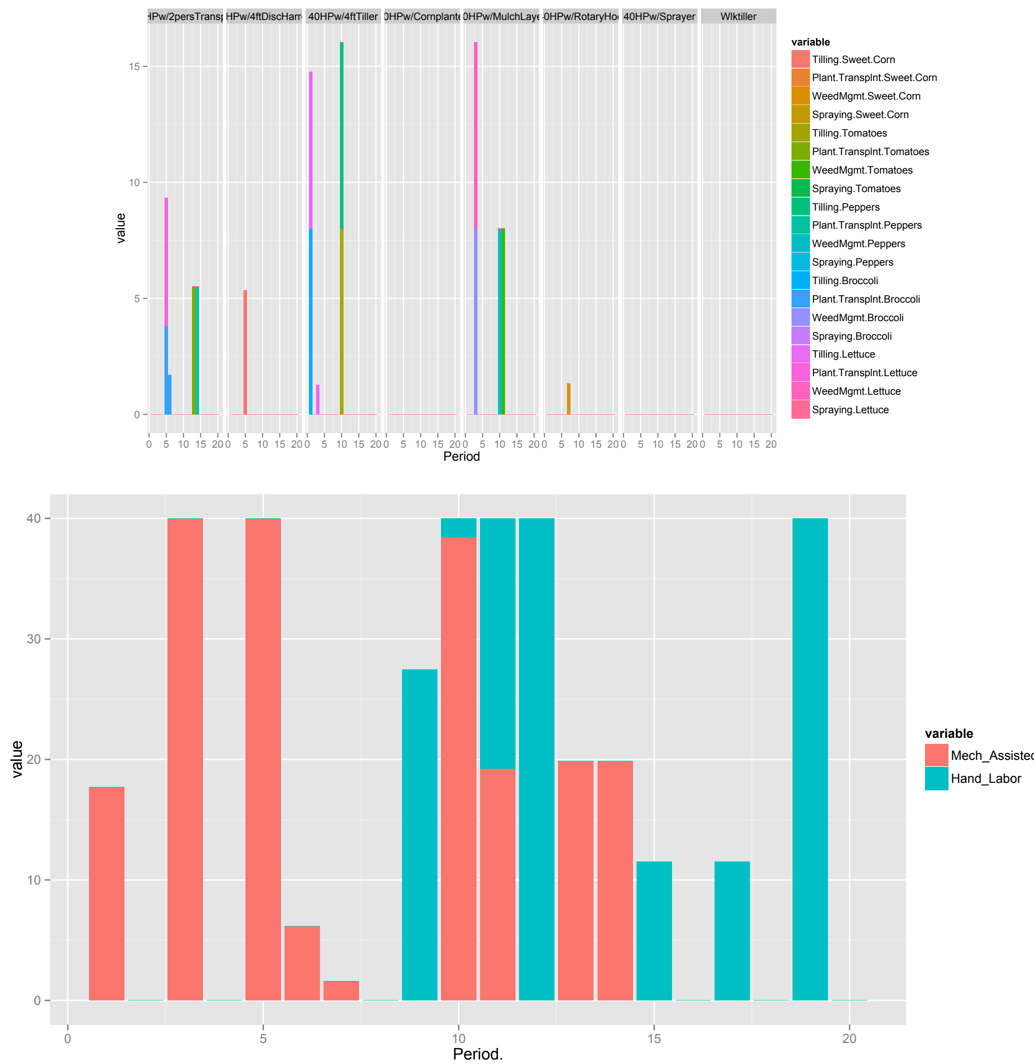

Figure 4.12: Machine and Labor Profile After a Sweet Corn-Skewed Diversification Expansion

4.5.0.12 Sharing Arrangement

The final simulation will be a sharing agreement between two farmers considering sharing a corn planter. To simulate this arrangement, we will need to treat the sweet corn crops between the two farms as separate "crops" in the model. This is because in this arrangement, like many sharing arrangements, divides the implement's time between the two farms. The goal for the model is to determine if this sharing arrangement is possible. We will assume that crops between two farms are the same and with the same acreage except for corn acreage. We will assume

Table 4.21: Acquisition Table Before a Diversification Expansion

Machine Purchase	Original	4 ft. Rototiller	4 ft. Disk Harrow	15 ft. Corn Planter	Transplanter	Mulch Layer	15 ft. Rotary Hoe	80 ft. Pull-Type Sprayer
	Original Used	1	1	0	1	1	1	0
Optimized Cost	$5,310.78	$5,310.78	$5,310.78	$4,601.57	$5,310.78	$5,310.78	$5,310.78	$4,380.17
Difference from Original	$0.00	$0.00	$0.00	-$709.21	$0.00	$0.00	$0.00	-$930.61
Max. Weekly Labor Allocation	40 hours	40 hours	40 hours	40 hours	40 hours	40 hours	40 hours	40 hours
Difference from Original	0 hours	0 hours	0 hours	0 hours	0 hours	0 hours	0 hours	0 hours
Purchase Price	–	$6,600	$800	$17,500	$5,995	$5,400	$3,300	$16,500
Seasons to Recoup Purchase	–	–	–	25	–	–	–	18

that the farmer from the previous simulation is considering sharing a planter with a farm that has a smaller level of corn (4.22).

First we compare the acquisition tables for each of the two farms to get the cost reductions from a corn planter for each of the two farms. An accurate depiction would take the periodic constraints of the sharing contract. In this simulation, the corn planter is the only implement that is able to complete the task of planting corn (Table 4.10). By examining the optimal time table, corn planting can take place over weeks 9 through 14 (Table 4.13). We construct the contract so that each farm gets access to the planter on alternating weeks. The first farm gets the planter on weeks 9, 11, and 13 and the second farm gets the planter on weeks 10, 12, and 14. From the point of view of the programmer, this constraint is subtle since it should allow hand labor hours and other machinery hours to be applied in these periods. A modified optimal time table is incorporated to the machine portion of the intertemporal equality constraint of the model. Since the two farms are identical except for corn acreage, the benefit from a corn planter for the second farm is half of the cost reductions of the first farm (Table 4.23). The simulation for each individual farm with the constrained corn planter time was successful meaning that this arrangement is feasible so that each farm can complete all of their farm tasks. If farms were to purchase and share the corn planter, they would save $1,063.81 between the two of them.

Table 4.22: Sharing Farms Acreage

Sharing Farm	Sweet Corn	Tomatoes	Peppers	Broccoli	Lettuce
1st Farm	10	2.88	2.88	2.88	2.88
2nd Farm	5	2.88	2.88	2.88	2.88

4.6 Model Conclusions and Extensions

In spite of the potential that the model has for farmers there are still improvements to be made. As it currently stands, the overall work rate assumptions may be imprecise. Without a set of experimental data, these rates are calculated with the theoretical machine capacity times a constant efficiency rate. The model would benefit considerably if there were a set of data from farmers and experimental farms to compute realistic efficiency rates for each machine. Weather

Table 4.23: Cost Savings from a Corn Planter Individually and Through Sharing

	1st Farm		2nd Farm	
Machine Purchased	Original	15 ft. Corn Planter	Original	15 ft. Corn Planter
Optimized Cost	\$5,310.78	\$4,601.57	\$4,638.68	\$4,284.07
Difference from Original	\$0.00	-\$709.21	\$0.00	-\$354.61
Max. Weekly Labor Allocation	40 hours	40 hours	40 hours	40 hours
Difference from Original	0 hours	0 hours	0 hours	0 hours
Season to Recoup Purchase Individually	–	25	–	50
Seasons to Recoup Purchase While Sharing	17			

does not enter the model. In a given week, approximately 45% of the hours are unworkable partly due to climate and precipitation issues (Landers (2000), pp. 18). By examining weather patterns, a distribution of the proportion of workable field hours may be created for each week. With the proper data, R has the ability to construct and perform random draws from each of these distributions to show how a less predictable season would impact the costs savings that a machine would bring.

Under the framework of the model, several assumptions are made. Firstly, the model exhibits constant economies of scale. Doubling acreage will double the required hours needed to complete these tasks. Two workers working together are assumed to be just as productive as two workers working independently. Additionally, output is exogenous to labor and machinery decisions. The revenue side of the profit function is fixed for the level of production. Once a farmer decides on the level of acreage, output is assumed constant over machine and labor choices. This goes against some of the testimony of the case farms. Farmer #1 said that using mulch increases the output and quality of crops. Farmer #5 said that laying mulch for sweet corn increases yields. While these are both valid concerns, since many growers engage in direct marketing, the revenue side of the profit function is still difficult to model on the basis of price. Finally, machine hours and hand labor hours differ only by their efficiency rates and costs. This may not be the case since larger equipment may not be as precise as hand labor. Larger seeders may result in more seed waste and transplanters may be less precise. These disparities are likely minor but they are worth addressing.

The above section demonstrates the ability for this software to simulate expansions and machinery acquisition by purchase or by sharing. Viewed with the comments from case farms, the simulation results are fairly consistent with what farmers have encountered. As farms became larger, mechanization becomes more economically justifiable and necessary to maintain production. Mechanization may also help even out work over the course of the season. What makes this model especially useful is its adaptability. Location can impact the timing of farm tasks. Further technological and horticultural developments can impact both task timing and the efficiency and costs of machinery. These alterations can be easily incorporated into the model. This makes this model particularly useful to farmers who keep field diaries.

CHAPTER 5. SUMMARY AND CONCLUSION

Increasing the size of fruit and vegetable farms is a difficult problem. Farmers in the Midwest face higher labor wages potentially and lower access to migrant workers than their counterparts in the western and southern states. Mechanization may help farmers scale up their production by offsetting labor costs. Case farmers suggested that machines do indeed reduce labor but certain crops are more difficult to mechanize than others. Harvesting remains a task that for many crops must be done by hand. However, farmers are beginning to mechanize in other ways to improve cost effectiveness. Planting, weed management, and spraying are three general tasks where machines have the potential to replace labor. A plastic mulch layer can lay approximately 36 times more plastic in an hour than performing that task by hand. Farmers choose to mechanize for a variety of reasons. Case farmers purchased machinery to improve timeliness, to offset labor, and to reduce stoop labor. Machinery is often an expensive investment and farmers generally approach purchases with a degree of caution. Some purchase machines based on what they've encountered in previous employment, others perform their own research by renting or borrowing equipment to find the best equipment for their needs. Over 80% of the surveyed farmers are willing to share equipment but timeliness remains a concern.

The model presented earlier presents a way to bring economists, horticulturalists, and engineers together to address input questions of farmers. It is able to address the context of timeliness and machine-to-task compatibility to show the impact that a machine acquisition would have on the farm's costs and the feasibility of farm expansion. It can be easily modified to conform to new technologies, crops, and efficiency rates. It may also be modified to handle weather related shocks in future iterations. There are potentially binding size constraints in its current form, a consequence of the software that it runs it. In R, models of this type can only accommodate 10,000 choice variables, a constraint that can be easily reached as it considers more tasks, crops, periods, and machines. There are other packages that have higher computing power than R but none to the author's knowledge are free. As software becomes more powerful and available as open source, farmers may be able to make more comprehensive simulations in the future. This, in addition to more farm-level data, will make simulations more realistic and useful for addressing machinery concerns.

AppendixA. Survey Copy

ISU Research Survey: **Fruit and Vegetable** Farm Machinery Use in Iowa

The objective of this survey is to gather information on the type of machinery and equipment used on vegetable and fruit farms in Iowa. The information will be used to develop decision-making tools for evaluating machinery adoption. **Please Note:** This study is for research purposes only. Your identity will be confidential. Participation in this survey is voluntary.

Background Information

1. Where is your farm located? County:____________ State: _______________

2. How many years have you been growing vegetables and/ or fruit? __________ Years

3. About how many acres of vegetables do you grow? About how many acres of fruit?

______________ Acres of vegetables ______________ Acres of fruit

4. What are the primary vegetable crops you grow? ____

What are your primary fruit crops? ____

5. Indicate below if you raise livestock or grow other agricultural crops – give approximate acres/herd size.

_________________________Row Crop (acres) _________________________Pasture (acres)

_________________________Forage (acres) _________________________Livestock (number, type)

6. Including yourself and any family members, how many people do you employ?

Months	# Full Time	# Part Time	Average Hours Worked Per Week
December - February			
March - May			
June - August			
September - November			

Machinery/Equipment Practices and Needs

7. Do you currently share any equipment or machinery with other growers? Yes No
If yes, please briefly describe your sharing arrangement (what is shared and how).

____

8. Would you consider sharing equipment or machinery with other growers? Yes No
If yes, please briefly describe the type of equipment you would consider sharing.

____

9. Do you currently perform any custom work for other growers? Yes No
If yes, please briefly describe the type of custom work you do.

____

10. Do you plan to expand your operation in the next 5 years? Yes No
If yes, what are the most important machinery/ equipment items you would need to acquire?

____

Fruit and Vegetable Field Machinery and Equipment

Please list the machinery/equipment used in your fruit/vegetable operation and provide a brief description (including size) in the space provided below. Indicate whether you **own, rent, or custom hire in** each type of machinery with a check mark (✓) and please **rank the 5 most critical items** for your current operation.

Equipment/Machinery (with examples)	**Brief Description (e.g. # of rows, horsepower, brand, width, self-propelled, pull-type, push etc.)**	**Own**	**Rent**	**Custom Hire In**	**Rank Top 5 1-high 5-low**
Mulch Layers /Lifters (3' plastic layer w. irrigation attachment, straw mulcher)	1.				
	2.				
Bed Shapers (bed shaper sled, double disc bed shaper)	1.				
	2.				
Cultivators (2 row sweep cultivator)	1.				
	2.				
Tillage (3 shank chisel plow, rototiller, 2 shank subsoiler)	1.				
	2.				
Transplanter (3 point hitch water wheel planter)	1.				
	2.				
Sprayers (tractor mounted mist sprayer with 50 gallon tank)	1.				
	2.				
Seeders (3 row drill-type, 4 row plate planter)	1.				
	2.				
Fertilizer Spreaders (100 lb gravity flow mounted; 6' pull type drop spreader)	1.				
	2.				
Harvest Equipment (1 row 3point hitch potato digger)	1.				
	2.				
Tractor	1.				
	2.				
Pickup truck/ Van	1.				
	2.				
Other (Please list)	1.				
	2.				

Thank you for taking this survey.

AppendixB. Case Study Question List

Table B.1: Farm Characteristic Questions

FARM CHARACTERISTICS	
Question	Justification
Describe the primary crops that you grow. Fruits? Vegetables? Approximate acreage for each?	Not all crops have the same requirements. Some crops have few mechanical substitutes to hand labor. Annual crops for instance do not need to be planted every year. The feasibility of mechanizing tasks may depend on the amount of acreage a farm has for a particular crop.
Are there any other operations on your farm such as livestock or other crops that you grow? If so, describe them and their impact on your machine and labor decisions.	Labor and some machinery are versatile farm inputs and may have uses in many activities aside from fruit and vegetable production.
Do you use any implements for both produce and other operations? Tractors, trucks, etc.?	
About what portion of your output is processed and what portion is bound for fresh FV consumption? What portion of your production is sold wholesale versus retail? What are your primary marketing outlets?	Mechanical harvesting for crops bound for processing such as wine grapes or jams may be more feasible since any damage may be less visible to the final consumer.

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Table B.2: Labor Questions

LABOR	
Question	Justification
How many workers do you employ throughout the year (part-time/ full-time)? Does employment change by season? If so, how so?	Farmers may use machinery to offset labor costs. Labor employed throughout the year gives context to machine acquisition decisions.
How many purely seasonal/non-family workers do you employ and how long do you employ them? How easy is it to find seasonal workers?	Mechanization may be more prevalent among farms if it is difficult to obtain labor. This may be especially prevalent if the farm heavily relies on seasonal workers since it does not provide consistent employment throughout the year.

Table B.3: Machinery Questions

MACHINERY	
Question	Justification
Including rented, custom hired, and owned, what machines or equipment are used on your farm? Can you describe them?	This puts the characteristics of the machine fleet into context of the other features of the farm. Renting or custom hiring avoids the fixed costs of ownership and may promote mechanization.
Do you own, rent, or custom-hire these implements?	
What were some deciding factors into buying/renting/ custom hiring implements in your FV operation? At what point were those changes were made?	This provides a description of farmers' decision-making process by asking how farmers make their decisions.
When looking to update machinery did you consider any alternatives?	Discussing alternatives is important since they are not observed decisions of the farm. Knowing why machines are not acquired gives insight into why certain machines are not as sensible.
Did the adoption to any of your machinery involve changing crops and or production style to accommodate them?	The adoption of certain mechanical systems may require changes to the farm's crops or layout. This may discourage the use of equipment or expanding acreage.
What are the top 5 implements that you use in your fruit and vegetable enterprise (what are the implements that would be especially hurtful if you lost them?) and why?	Explains why certain machines are more important than others. This ordinal ranking may show what machines should be purchased first for other farms with similar characteristics.

Table B.4: Machinery Practices Questions

MACHINERY PRACTICES	
Question	Justification
Do you currently share any implements with any other growers? If yes, describe what you share and why (lack of custom operations to fill the need etc.).	Some machines may be easier to share for certain reasons. Certain machines may be too expensive to unilaterally own but would beneficial in a joint arrangement.
Do you currently perform any custom work for other growers? If yes describe what custom work you do. How far you would be willing to travel to provide custom services. Is yours the only custom operation that provides these services in your area?	Performing custom work may incentivize machine purchases since they provide a stream of income to the owner.

Table B.5: Expansion Questions

EXPANSIONS	
Question	Justification
Please give a history of your farm including how it started, any expansions that took place, and any major purchase of machinery or additions to labor.	This provides a record of the decisions made on the farm and explicitly links them to the contextual features of farm expansions.
Do you plan on expanding in the next 5 years? If yes, describe your plans and obstacles that you may see you need to overcome to meet your expansion goals. Please explain why you are expanding (increased profits from high demand, newly available land etc.). If no, are there any factors that are preventing you from doing so?	Expansions are of key interest to the study. The type of expansion may impact the types of challenges that growers face and the role machines would serve. Farmers may purchase machines in anticipation of future expansions. Conversely, labor or machinery considerations may impact whether future expansions are planned at all.

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