Effects of Farm and Household Decisions on Labor Allocation and Profitability of Beginning Vegetable Farms in Virginia: a Linear Programming Model

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ABSTRACT

The United States is facing a rising average age of principal farm operators and a decline in number of beginning farmers. With numerous barriers and challenges resulting in many farm failures, a majority of beginning farmers are relying on off-farm income to support their households. Decision-making and farm business planning are difficult skills to develop and improve, and the ability to develop a plan to balance on- and off-farm labor could allow farmers to make more profitable decisions. In this study, a General Algebraic Modeling System (GAMS) is used to develop a labor management planning framework for use by Virginia's beginning vegetable farmers or service providers, such as extension agents, with the goal of improving total (on- and off-farm) profitability and farm viability. Study findings suggest that a willingness to work of 12 hours per day, 365 days per year and hired labor costs of $9.30 per hour, which is the national average for agricultural workers encourage a farmer to maintain an off-farm job, while a relatively lower off-farm wage or salary may encourage a farmer to work on the farm only. Lastly, higher hired labor costs may encourage a farmer to pursue his or her most profitable work opportunity, be it on- or off-farm, without hiring labor to maintain the farm. The model developed in this study may be used to plan multiple years of farm management to include anticipated changes in off-farm employment opportunities, land availability, product mix, and access to farm labor. The author suggests that beginning farmers who use this planning tool are able to make more informed decisions related to allocation of labor time and resources, resulting in lower failure rates for beginning farmers in Virginia. A user-friendly interface may be

developed based on the study framework, to strengthen the results and increase the practicality of the tool.

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GENERAL AUDIENCE ABSTRACT

The United States is facing a rising average age of principal farm operators and a decline in number of beginning farmers. With numerous barriers and challenges resulting in many farm failures, a majority of beginning farmers are relying on off-farm income to support their households. Decision-making and farm business planning are difficult skills to develop and improve, and the ability to develop a plan to balance on- and off-farm labor could allow farmers to make more profitable decisions. The framework developed in this study could be used by extension agents and agricultural service providers to advise farmers in making labor decisions. By entering the farmer's household and farm information into the labor decision tool developed in this study, the extension agent or service provider may present their clientele with specific advantages and disadvantages associated with the most profitable labor allocation suggested by the model. Using the tool developed in this study may improve long-term success of small-scale beginning farms in Virginia by providing a method for mapping out the consequences of specific farm labor decisions on expected farm profits.

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CHAPTER 1: INTRODUCTION

Overview of Virginia Agriculture and Beginning Farmers in the United States

At the time of the 2012 United States Department of Agriculture (USDA) Census of Agriculture, Virginia had 46,030 farms. These farms totaled to 8.3 million acres of land, with the average farm covering 180 acres. According to USDA definitions, 70 percent of Virginia farms were classified as small farms[1], and 26 percent of Virginia's farmers were classified as beginning farmers[2]. The diversity of Virginia Agriculture is illustrated in Figure 1. The majority of farms in Virginia are dedicated to livestock operations specializing in broilers, cattle, hogs, sheep, and turkeys. In terms of crops grown, Virginia farmers specialize in corn, wheat, soybeans, forage, nursery crops, tobacco, peanuts, and vegetables. Vegetable farms make up 3.5 percent of Virginia's farms, 2.5 percent of farm cash receipts, and less than one percent of total acreage. However, low farm count and acreage do not accurately reflect the significance of vegetable crops in Virginia, as fresh tomatoes and potatoes, for example, are two of Virginia's most productive crops in terms of value of production (USDA NASS, 2014b).

According to the USDA Economic Research Service (ERS), beginning farmers are less likely to specialize in grains, row crops, and dairy than established farms (Ahearn, 2013). The most common specialty among both beginning and established farmers is beef cattle, but established cattle enterprises outnumber beginning enterprises. Beginning farmers outnumber established farmers on enterprises that grow specialty crops such as fruits, vegetable, and nursery

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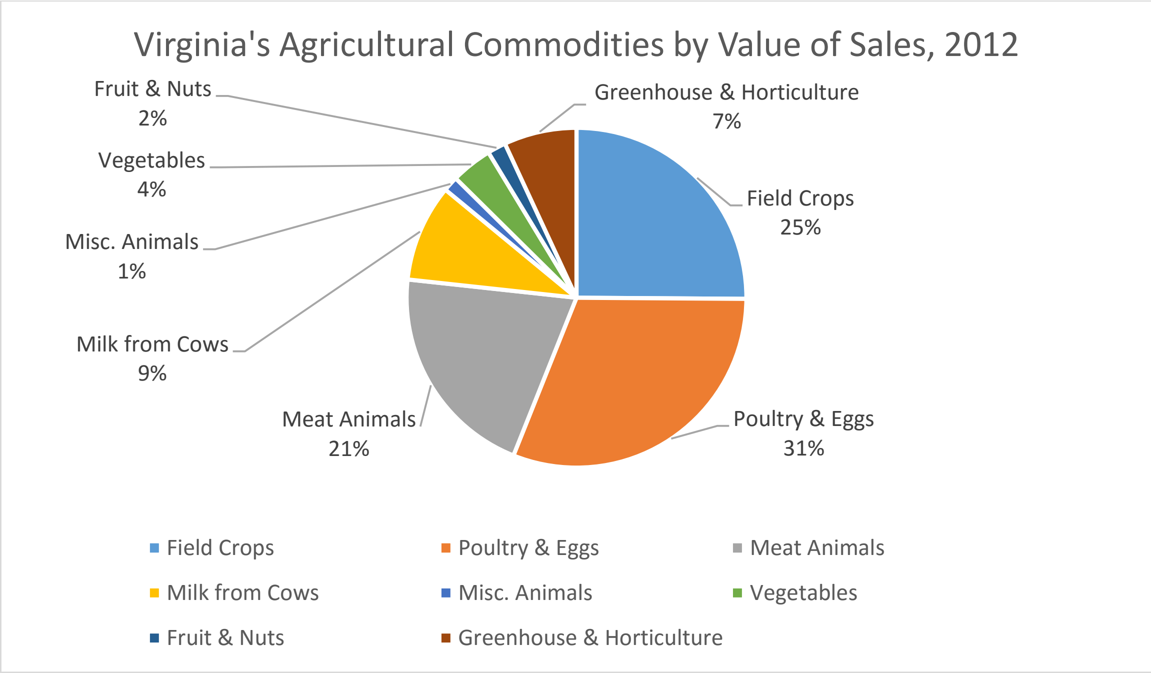
[1] The USDA defines a small farmer as one that grows and sells between $1,000 and $250,000 per year in agricultural products (Hoppe, MacDonald, & Korb, 2010).

[2] A beginning farmer is defined by the USDA as those who have operated a farm or ranch for 10 years or less, either as a sole operator or with others who have operated a farm or ranch for 10 years or less (Ahearn & Newton, 2009). In this study, any farmer who does not fall within this definition of a beginning farmer will be labeled as an established farmer.

crops; raise hogs and poultry; and multi-enterprise farms (farms on which no single commodity accounts for 50 percent of the total value of production).

Figure 1: Virginia's Agricultural Commodities by Value of Sales in 2012 (USDA NASS, 2014b)



When the traditional commodities of beginning farmers are contrasted with those of established farmers, it becomes apparent that beginning farmers and ranchers may start with a broad number of crops and livestock and specialize in later years, if at all, when they have gained more experience. This idea is supported by a study conducted by Chavas (1993), who concluded that the economies of scope tend to be very large for small farms, implying that small farmers see more benefits from having a diverse production plan.

Problem Statement

The 2012 USDA Census of Agriculture noted the rising average age of principal farm operators[3] is continuing. Between 2007 and 2012, the average age of principal operators increased by two percent to 58.3 years, a continuation of a thirty-year trend. Only six percent of

[3] In this paper, a principal operator of a farm is the person who runs the farm. Not all principal operators are considered owners, as many farmers rent land.

principal operators were under 35 years old, with 61 percent between the ages of 35 and 64, and 33 percent at an age of 65 or older (USDA NASS, 2014d). A second trend noted in the 2012 USDA Census of Agriculture was fewer beginning farmers. The number of beginning farmers decreased 20 percent from 2007. Only 26 percent of principal farm operators were beginning farmers, compared with 38 percent in 1982 (Ahearn, 2013). Increases in consolidation and farm size, productivity, or additional land in farming are options available to avoid a decrease in production in the United States as America's farmers retire in the coming years. There is no "one size fits all" solution to which of these approaches should be selected. Rather, this decision is made based on personal and societal preferences, opportunity, technology advances, and a number of both internal and external factors.

When farmers leave their operations, their farmland may be consolidated under another farmer's care in order to leave the amount of total farmland in production unaffected. However, between 2007 and 2012, the number of farms was down by 4.3 percent nationwide, and land in farms was down by 0.8 percent (Vilsack, 2014). These decreases illustrate that, while some farmers may be consolidating farmland from exiting farmers into their current operations, some farmland is being taken out of production for various reasons (e.g. no individual willing to continue farming, land not suitable for production, urbanization).

It is possible for yields to increase, requiring fewer inputs and land area to achieve the same level of output. According to the USDA Economic Research Service (ERS), the average annual growth rate of farm output productivity between 1948 and 2011 was 1.49 percent (USDA ERS, 2015a). If this average holds for future years, reduction in number of farms and acres of farmland may be counteracted by increased productivity. The growth rate of farm output productivity is dependent on technological change, genetic improvements, and mechanization. It is impossible to predict how these factors will change in the future, and it is difficult to estimate how the growth rate will be affected. However, with an estimated half a million American farmers retiring by 2030, increased productivity alone may not be sufficient to keep overall production from decreasing (Shute, 2011).

An increase in the number of farms (on land not currently in production, not splitting existing land into smaller segments) could lead to an increase in production, but beginning farmers face a high failure rate[4] compared with established farms. The 2007 Agricultural Resource Management Survey (ARMS) showed that 45 percent of farms that entered into business between the 1978 and 1982 censuses were still in operation after their first 5-9 years. However, 63 percent of farmers who survived this first period stayed in operation after 10-14 years, and 68 percent of those farmers who survived the second period stayed in business after 15-19 years. Overall, these data revealed that those with less farm experience have higher failure rates (Ahearn & Newton, 2009). While this time period was an era of farm financial crises, beginning farmers today continue to face difficulties compared with their established counterparts.

In addition to being more likely to fail, beginning farmers earn less income from their farms. The difference in household farm earnings between beginning and established farmers is illustrated in Table 1, and the characteristics of beginning and established farms in 2007 are compared in Table 2. Beginning farms tend to be smaller (when measured in both sales and acreage) than established farms – 174 acres compared with 461 acres (Ahearn & Newton, 2009). A smaller size is not beneficial for beginning farmers, as these farms are likely to grow and sell less than larger farms. These small farms (in terms of sales) have an exit rate[5] of 9-10 percent per

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[4] An indication of the frequency with which businesses fail to stay in operation over time

[5] An indicator of the percent of businesses that ceased operations in a given year.

year (Hoppe & Korb, 2006). Exit rates decline as farm size increases, with the exit rate of large farms[6] at 6-7 percent (Hoppe & Korb, 2006). This large farm exit rate is equivalent to the annual exit rate for all agricultural and non-agricultural businesses (Smith, 2013).

Understanding why beginning farmers fail is important to providing knowledge of how to address barriers to entry and obstacles during the startup years. In 2011, the National Young Farmer's Coalition (NYFC) surveyed 1,300 people from 34 states, 81 percent of whom were farmers (Shute, 2011). Fifty-six percent of those who identified as farmers had between one and five years of experience working on farms, and 87 percent met the USDA definition of a beginning farmer. The most important obstacles and barriers identified by respondents were access to capital (78 percent), and access to land (68 percent, health care (47 percent), access to credit (40 percent), business planning and marketing skills (36 percent), profitable markets (30 percent), and education and training (26 percent). These obstacles will be discussed in more detail in Chapter 2.

Table 1: Household Farm Earnings (in dollars per principal operator household), Beginning vs. Established Farms, 2007 (Ahearn & Newton, 2009)

Established Farms	Beginning Farms	All Farms
14,446	-1,253	11,002

Table 2: Characteristics of Farms and Production Status, Beginning vs. Established Farms, 2007 (Ahearn & Newton, 2009)

	Established Farms	Beginning Farms	All Farms
Percent of Farms	78	22	100
Average Acres Operated	461	174	398
Percent of Acres Operated	91	9	100

McAleer (2012) of the National Institute of Food and Agriculture reported lack of production and management skills as reasons why new farm enterprises fail. Klinefelter (1989)

[6] Sales of $250,000 or more

compiled a list of common causes of farm failure, which includes: lack of management ability, inadequate information, insufficient monitoring, poor money and time management, inadequate attention to personnel management, attempting to support too many people from the operation, and more. With these obstacles to overcome, the number of beginning farmers who are able to remain in production is limited.

U.S. farm policy has been put in place to reduce the barriers to entry faced by beginning farmers. For example, the 2002 Farm Bill directed the USDA to create programs that would help beginning farmers. These programs involved improved access to short and long-term financing for operating funds and real estate and machinery loans (Young, 2008). However, according to the 2009 ARMS survey, 24 percent of beginning farmers participated in direct payment programs, compared with 41 percent of established farmers. Direct payments are awarded according to acreage and yields, so when beginning farmers do participate in direct payment programs, they generally receive smaller payments (Ahearn, 2011). Some loan organizations, for example, the USDA Farm Service Agency, offer specific loans to beginning farmers and ranchers for which established farmers are unqualified (USDA FSA, 2012).

The 2002 Farm Bill also authorized the Beginning Farmer and Rancher Development Program (BFRDP). The BFRDP is directed at training new and beginning farmers by means of awarding grants to certain institutions dedicated to the education of these farmers. In 2008, the program received $19 million per year in funding. The 2014 Farm Bill reinforced the ongoing need for this program by providing it with an additional $20 million per year in funding through 2018 (NSAC, 2014b). The 2014 Farm Bill also made other strides to help beginning farmers by means of credit improvement, outreach programs, and improving the competitiveness of beginning farmers and ranchers (NSAC, 2014a).

A growing number of universities, nonprofit programs, and other organizations are directing training programs for new and beginning farmers, specifically. (Niewolny & Lillard, 2010). Agricultural service providers

Rationale and Significance

A commonly cited statistic underlying the importance of encouraging beginning farmers to launch and maintain profitable operations is in regards to global food security. With a rising global population, it is projected that food production will need to increase by 70 percent by 2050 in order to meet demand (Ranganathan, 2013). Implementing sustainable practices to decrease negative environmental impacts of agriculture, improving access and availability of food, reducing food waste, and boosting crop yields per acre are all steps to be taken in order to reach this goal. Each of these steps requires technological improvements, policy changes, and/or paradigm shifts among current farmers and consumers. In the meantime, increasing the number of farms and farmers in the U.S. may also increase production and positively affect global food security.

An increasing demand for local or American-grown food products is yet another incentive to support the success of beginning farmers. According to a Consumer Reports National Research Center survey, 78 percent of Americans would rather buy an American product over its counterpart that came from abroad (“Knowing Which Products”, 2013). Some consumers buy within even more specific growing locations, preferring goods grown in specific regions, states, or even cities. An increase in the number of farmers markets across the United States illustrates an increased demand for local food. The number of farmers markets rose to 8,284 in 2014, compared with 1,755 in 1994 (ERS, 2014). This increasing demand for local foods can only be met with an increase in supply, which America's farmers have the opportunity to offer.

A third issue of increasing concern is the decline of rural America. Rural America and farmers support each other, and the decline of one leads to a decline in the other. According to the USDA ERS, changing demographics in rural America include an aging population, an outflow of young adults, and an inflow of older adults (Kusmin, 2014). Because of this flow, birth rates in rural America are declining. Among this declining population, rural employment remains below levels before the Great Recession of 2007-09. As many farmers live in rural areas, higher success rates for beginning farmers may rebuild and strengthen the failing communities and economies. The stronger communities and economies could then attract a newer, larger generation of farmers and end the cycle of decline in rural America.

Training and educating beginning farmers will have positive impacts on their long-term success. One form of training that benefits new farmers, and the focus of this study, is farm planning for expansion. Ahearn (2009) noted the importance of growth to beginning farmers:

> A common startup strategy for any business is to start small. For that strategy to be successful in the long run, the business plan must include growth to an optimally efficient farm size, depending on what that is for the farm's specialty and region. (p. 21)

Knowing how to allocate labor and resources during start-up and expansion in order to increase farm sustainability and goal attainment is a vital skill. The inability to do so ties into many of the causes of farm failure listed above, as inadequate labor and resource management will increase costs and cause production and management inefficiencies.

The dominance of small farms, low number of beginning farms in Virginia, importance of vegetable crops to Virginia in terms of cash receipts, and popularity of specialty crops among beginning farmers in the United States are all reasons that this study will model small, beginning vegetable farms in Virginia.

Objectives

The main objective of this study is to develop a labor management planning tool that can be utilized by Virginia's beginning vegetable farmers in order to improve total (on- and off-farm) profitability and farm viability. This tool will detail optimal allocation of on- and off-farm labor. To achieve this goal, it is important to address the following sub-objectives:

- To analyze how a beginning farmer's debt and land access affect the long-term profitability of the farm enterprise;
- To describe how and why on- and off-farm income and expenses determine the number of hours that a farmer spends on the farm; and
- To determine how changes in labor allocation affect profitability using a baseline model.

Methods and Data

Determining the effects of labor management decisions on the profitability of small, beginning vegetable farms in Virginia will be accomplished by developing a baseline linear programming model of a Virginia vegetable farm, then creating alternatives (such as large amounts of land, low willingness to work, high labor costs, low off-farm income, and high debt) to the baseline model to see how the optimal solutions differ.

Thesis Organization

Background information regarding beginning farmer characteristics, factors affecting financial stress of farmers, farm management and decision-making, profit maximization and alternative behaviors, and the effects of off-farm labor on farm families is provided in Chapter 2. In Chapter 3, an outline of the conceptual framework of the model used to represent a Virginia farmer, techniques of analysis, and data used for estimation in the model is provided. The results of the model and discussion of the modeled scenarios are presented in Chapter 4. Finally, Chapter 5 includes a summary, practical implications of this work, and a discussion of future work to be done in the area of modeling farm labor decisions.

CHAPTER 2: LITERATURE REVIEW

Beginning Farmer Characteristics

The 2012 USDA Census of Agriculture found beginning farmers to be slightly younger than established farmers (Table 3). While established farmers had an average age of 61.4 years, the average ages of farmers on their current operations for six to ten years or five years or less were 50.8 and 46.9, respectively. The census stated that "beginning farmers were also more likely to be female than established farmers, more likely to be minority, more likely to spend some time working off the farm, and less likely to consider farming their primary occupation" (USDA NASS, 2014c).

Table 3: Principal Operator Characteristics by Years on Current Farm in 2012 (USDA NASS, 2014c)

	All Farms	**Years on Current Farm**		
		1 to 5	6 to 10	11+
Number	2,109,303	226,670	295,388	1,587,245
	Percent of principal operators in group			
Age				
<35 years	6	24	14	1
35 to 64 years	61	64	70	59
65+ years	33	12	16	40
Gender				
Female	14	18	17	12
Male	86	82	83	88
Race/Ethnicity				
White (non-Hispanic)	92	90	90	93
Minority	8	10	10	7
Primary Occupation				
Farming	48	37	37	51
Other	52	63	63	49
Worked Off the Farm				
Yes	61	77	73	56
No	39	23	27	44
Average Age (years)	58.3	46.9	50.8	61.4

The average farm based on years on the farmer's current operation in 2012 is described in Table 4. Beginning farmers were also more likely to have smaller farms (both in sales and acreage), received less government aid, and had higher average expense-to-sales ratios than established farmers (USDA NASS, 2014c). The conclusion that beginning farmers face higher total costs than established farmers is supported by a study conducted by D'Antoni, Mishra, and Chintawar (2009).

Table 4: Average Farm by Years Principal Operator on Current Farm in 2012 (USDA NASS, 2014c)

	All Farms	**Years on Current Farm**		
		1 to 5	6 to 10	11+
Farmland (acres)	434	294	277	483
Cropland harvested (acres)	244	118	131	278
Value of land and buildings ($ millions)	$1.1	$0.6	$0.7	$1.2
Income and expenses ($)				
Agriculture sales	$187,097	$106,197	$125,269	$210,156
Government payments	$9,925	$7,220	$7,462	$10,504
Production expenses	$155,947	$96,673	$111,396	$172,703
Percent of operators with net gain	46%	39%	37%	48%
Expense to sales ratio	83%	91%	89%	82%

Rantamaki-Lahtinen and Vare (2012) conducted a study on how farmer characteristics, strategic objectives, and development plans differ between beginning and experienced farmers in south-western Finland. The researchers found that beginning farmers tended be less profitable and more educated, invest more heavily, have higher liabilities, and appreciate the social and environmental aspects of farming less than their experienced counterparts. There was no difference between the beginning and experienced farmer groups in terms of income structure of the farm families, farm diversification, or farm size.

D'Antoni, Mishra, and Chintawar (2009) found that beginning farmers lack experience compared with established farmers. However, being in the first ten years of a farm operation does not mean all beginning farmers have no prior farming experience before starting their current operations. The 2012 Census of Agriculture found:

> The 226,670 principal farm operators on their current farm five years or less had operated a farm for an average of 7.1 years, and 39,821 of them had operated a farm for more than ten years (including both their current and prior operations).
>
> The 295,388 principal farm operators on their current farm six to ten years had operated a farm for an average of 11.1 years; a third (99,841) had operated a farm for more than ten years. (USDA NASS, 2014c)

While beginning and established farmers all produce agricultural products, every farmer does not have the same decisions to make. Differences in age, gender, race, farm size, experience, and attitudes create social contexts that are unique to each individual. The decision making processes of beginning farmers are affected by these frameworks and a study that models these decisions would be remiss without recognizing these cultural differences.

Challenges Facing Beginning Farmers

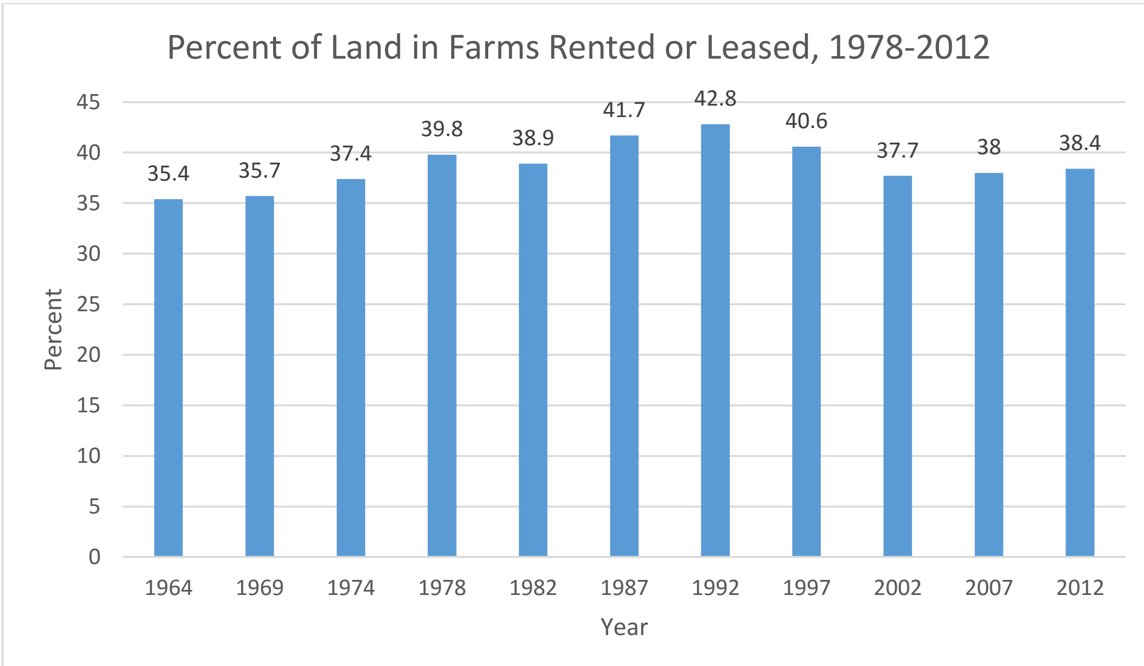
In 2011, the National Young Farmer's coalition (NYFC) surveyed 1,300 people from 34 states, 81 percent of whom were farmers. These farmers were asked to indicate which obstacles were most important to beginning farmers (with the option to select more than one obstacle). The seven obstacles identified by the NYFC, ranked by the survey respondents from biggest challenge to smallest, include: access to capital, access to land, health care, access to credit, business planning and marketing skills, profitable markets, and education and training (Shute, 2011).

Access to capital. Access to capital was identified by 78 percent of NYFC's surveyed farmers as an obstacle facing beginning farmers (Shute, 2011). Starting a farm is an expensive endeavor, and beginning farmers lack capital compared to established farmers (D'Antoni, Mishra, & Chintawar, 2009). Capital is needed for start-up and maintenance of the farm, including purchasing land, buildings, fences, equipment, and inputs such as seed or feed. The returns on a new farm, especially the small farms that beginning farmers tend to operate, may not be substantial enough to remain competitive in the market and support the farm families, driving beginning farmers to rely on off-farm income.

Access to land. The cost and availability of farmland were reported by 68 percent of NYFC's surveyed farmers to be challenges for beginning farmers (Shute, 2011). Although beginning farmers tend to have smaller farms (in acreage) than established farmers, land access is still problematic. Current farmland is being held in the hands of older farmers (Shute, 2011). These farms may be passed down to the next generation of farmers, but not all beginning farmers come from farm backgrounds and have the opportunity to inherit land from friends and family members.

Farmers who do not have the option of inheriting land must purchase or rent farmland of their own. Between 2000 and 2011, farm values across the United States doubled, from $1,090 per acre to $2,140 per acre (Shute, 2011). Farmers who have trouble finding affordable farmland to own often turn to renting land as an alternative. According to the 2012 Census of Agriculture, 62 percent of U.S. farmland is operator-owned. The percentage of farmland acres rented or leased by farmers in the U.S. between 1964 and 2012 is illustrated in Figure 2. Rented land has ranged from 34 percent to 43 percent between 1964 and 2012 (USDA ERS, 2015b).

Figure 2: Farmland Acres Rented or Leased from 1978-2012 (USDA ERS, 2015b)



Health care. Farming is a dangerous profession, ranking as the 8th most deadly job in the 2014 Census of Fatal Occupational Injuries (US DOL, 2015). Forty-seven percent of farmers surveyed in the NYFC study indicated that health care was an obstacle facing beginning farmers (Shute, 2011). Related to the issue of access to capital, farmers are using available funds to pay for the costs of health insurance when it is not covered by an off-farm employer. Farmers must not only provide health care for themselves and their families, but some may have to provide health insurance for farm employees.

Access to credit. Access to credit was identified as an obstacle for beginning farmers by 40% of farmers surveyed (Shute, 2011). This obstacle is closely related to lack of capital. Mishra, et al. (2002) found that lower-income and lower-wealth households, which are often beginning farmers, had low levels of consumption and lacked resources to help even out income during unexpected bad times. This led to the use of credit to cover costs and the accumulation of debt when capital was not available. The researchers found that beginning farmers had the highest on- and off-farm debt compared to established farmers.

Barlett (1984) conducted a study in south Georgia comparing full-time, part-time, and retired/disabled farmers. Barlett found that renters had higher debt and more bankruptcies than family-owned farms. The youngest renters, if faced with hardship, would encounter more losses and need more credit in order to sustain their operations. Farms with land ownership, available labor, and good management practices – often traits of more established farms – were least vulnerable to high debt in times of drought or lower harvest due to weather conditions.

Gaining access to credit may be difficult for farmers due to the inherent risk of farming. Organizations such as the USDA Farm Service Agency (FSA), seek to provide loans to farmers who have been turned down by commercial lenders. Problems reported by farmers related to taking advantage of these opportunities include: inconsistency in knowledge among lenders, inability to get small operating loans (rather than larger amounts), loan requirements disqualifying beginning farmers (e.g. required years of experience), and slow payments and low loan limits on direct loans (Shute, 2011).

Business planning and marketing skills. Business planning and marketing skills were identified as an important challenge facing beginning farmers by 36 percent of the farmers surveyed in the NYFC's study (Shute, 2011). Developing a business plan is an indicator of farm financial success (Mishra, et al, 2009). Not only are business plans helpful to farmers by allowing them to plan and evaluate the progress of their new enterprises, they also are often a key factor taken into consideration when applying for farm loans. The USDA Farm Service Agency (FSA) requires a business plan as part of the loan application (USDA FSA, 2012).

Marketing refers to a farmer's ability to promote and sell products to his or her intended customer base. A marketing plan, often part of a business plan, allows farmers to think about who their target customers are, how they will reach these customers, and how they will retain customers to ensure the financial success of their businesses. The development of these two documents takes time and effort on the farmer's part, but many resources have been developed to aid in this process.

Profitable markets. Lack of profitable markets was listed by 30 percent of farmers to be an obstacle facing beginning farmers (Shute, 2011). Accessing markets may be a physical or systematic difficulty. Some farmers may be physically unable to reach a market, due to location and technology (e.g. refrigerated trucks) limitations. Once at the market, farmers compete with each other to participate. In order to gain a customer base and earn higher returns, farmers aim to offer unique products in a market that is not yet saturated with the product they are offering. It is often difficult for beginning farmers to find a market that is accessible and suitable for their desires and skillset while differentiating their products from other farmers' and earning a profit.

Education and training. Education and training was identified as a challenge facing beginning farmers by 26 percent of farmers surveyed by NYFC (Shute, 2011). Training and knowledge are important to the success of a farm business. Due to the variable nature of the industry, farmers often must adapt quickly to unexpected changes and react to circumstances that are outside of the farmers' control. Many farmers opt to gain farm experience by apprenticing with established farmers before beginning their own enterprises. In addition, service providers have recognized that beginning farmers have different needs than established farmers and have begun to offer programs specific to this group (Niewolny & Lillard, 2010). Programs such as the USDA Beginning Farmer and Rancher Development Program (BFRDP) and Cooperative Extension have begun to make beginning farmer education a priority, resulting in numerous beginning farmer programs across Virginia and the United States.

Factors Affecting and Predicting Farm Financial Stress

D'Antoni, Mishra, and Chintawar (2009) investigated factors which could predict financial stress that young and beginning farmers would face. A multinomial logit regression model was used to analyze the farm's net farm income and solvency positions. This led to the formation of groups of either favorable (debts less than 40 percent of assets and positive net farm income), marginal solvency (positive-income, high-debt farms), marginal income (negative-income, low-debt farms), or vulnerable (debts in excess of 40 percent of the value of assets and negative farm income) farmers. Age, farm size, land ownership, years of farm experience, and farm type were all significant in determining financial stress.

Foreman and Livezey (2003) used a logit regression model to determine factors that contributed to the likelihood of financial success on rice farms. The researchers looked at the ratio of government payments to total production value, tenure, crop diversification, cost control, education, yield, and debt-to-asset ratios of rice farmers. Depending on how success was defined, the researchers found that education, farm efficiency, receipt of government payments, farm productivity, and debt-to-asset ratios helped some farmers be successful, while control of cash costs, the use of government programs, and renting land helped others.

Mishra, Wilson, and Williams (2007) investigated factors that contributed to the financial performance of new and beginning farmers. Specifically, this study measured financial performance given farmer characteristics, risk management strategies, and production and marketing strategies. In a weighted regression analysis, adoption of genetically modified crops, controlling variable costs, participation in certain farm payment programs, and participation in marketing contracts led to better financial performance. Increased education, age, and off-farm work were linked with lower financial performance.

Mishra, Wilson, and Williams (2009) used a weighted regression analysis to identify and measure factors that affect the financial performance of new and beginning farmers. Data on operating characteristics, the cost of production, financial condition, and well-being of farmers were taken from the Agricultural Resource Management Survey (ARMS). The researchers found once again that a farmer's age, education, and off-farm work were negatively correlated with financial performance. Increasing the number of decision makers, value-added farming, participating in government farm programs, and writing a business plan were linked to better financial performance.

A farm's financial performance is determined by a number of both tangible and intangible factors. Age, education, land ownership, experience, farm type, debt, off-farm work, and government payments are a handful of significant factors in predicting financial performance of a farm. As beginning farmers are often young, more educated renters with less experience and more off-farm work than established farmers, it is expected that these farmers would face more financial stress than established farmers.

Effects of Off-Farm Work

As previously stated, the 2012 Census of Agriculture reported that beginning farmers were more likely to spend some time working off the farm, and less likely to consider farming their primary occupation (USDA NASS, 2014a). In the survey conducted by the NYFC, over 73 percent of farmers reported that they depend on off-farm income (Shute, 2011). According to the

USDA Economic Research Service (ERS), a third of all farm households (686,600 total) in the U.S. in 2007 were engaged in some type of alternative income-generating activity. Of these households, 395,600 operated off-farm businesses. Of all the activities that farmers used to generate additional income, 50 percent were off-farm business ventures. Of the additional $26.7 billion income farmers generated, 80 percent was due to these activities (Vogel, 2012). In Virginia, 20,740 principal operators reported farming to be their primary occupation, while 25,290 reported “Other” (USDA NASS, 2014a). Whether they aspire to farm primarily or prefer to farm alongside another career, the majority of principal operators in Virginia are working both on and off of the farm.

Mishra, et al. (2002) found that young farm operators are more likely to pursue off-farm work because they are often more educated than older farmers. As a result, farms on average are seeing an increasing portion of household income coming from off the farm. On average, off-farm income accounted for 83 percent of farm operator household cash income in 2011 (Ahearn, 2013). The USDA ERS found that households operating beginning farms had higher average off-farm income and lower average farm income at every farm size (Ahearn, 2013).

Working off-farm in addition to farming has several effects on farm profit. If a principal operator and other family members are not capable of working the hours that the farm requires, the family may use machinery or change production to reduce the man-hours needed, or hire outside labor to maintain the farm operations. Hiring labor increases total costs to the farm household and will decrease total (on- and off-farm) profit. In addition, working off-farm may take the focus off of the farm’s success. Mishra, Wilson, and Williams (2009) found that new and beginning farmers who work off the farm in wage and salaried positions have 1.3 percent lower farm financial performance, measured by returns on assets[7]. While this is a small percentage, it illustrates the point that off-farm work can have a negative effect on the farm's ability to generate income.

While the farm itself may not necessarily benefit from off-farm work, these business ventures can benefit both the farm household and the communities in which the farmers are included. Farm households that pursued off-farm work earned incomes nearly twice the average for farm households who did not have alternative business activities in 2007 (Vogel, 2012). It is possible that the farm family holds off-farm work in order to make farming a possibility. Makinen (2013) found that one quality of successful farmers was a high appreciation of farming as an occupation. This could lead to the conclusion that farmers have a desire to farm and working off-farm brings in enough income to make farming a possibility when it, otherwise, may not be profitable enough to support the family.

The community impacts of non-farming businesses differ from those of commodity production, and the reach of the farm household's impact is extended when on- and off-farm work is pursued. While farm activities generate demand for farm inputs and impact other farm-related businesses in the community, pursuing off-farm work impacts the non-farm sectors. Rural communities have experienced growth as they have developed nonfarm business sectors (primarily the manufacturing and service sectors), and farm families now depend more on the local economy than the production of their farms (Irwin et al., 2010).

With more farm family income coming from off-farm and a majority of Virginia farmers reporting a primary occupation off of the farm, Virginia's farmers need to find a balance of on- and off-farm work that satisfies their personal desires while meeting the farm household's financial needs. This study is focused directly on this trade-off of labor and is intended to benefit

[7] Returns on assets (ROA) is the ratio of net farm income to total assets

farmers by maximizing household income as they seek to find ways to achieve balance between on- and off-farm employment decisions and total (on- and off-farm) profitability.

Decision Making on the Farm

Operating a farm requires long-term and short-term decisions to be made every day. These decisions may range from land and equipment purchases, to production plans, to labor allocation. A number of factors will determine what the “right” decision for an individual farm operator may look like each year.

Some qualities that lead to strong decision making on the farm are intrinsic. Tauer and Stefanides (1998) used the weak axiom of profit maximization[8] to test how successful New York State dairy farms were at maximizing profit. A tobit regression was performed on the characteristics of the 70 farms in the study. The researchers concluded that additional education and increased age had a positive effect on the ability to select the most profitable combination of outputs, while having more than one owner-operator had a detrimental impact.

Not all qualities that lead to positive decision making on the farm are inherent. Huffman (1977) used econometric evidence to illustrate that allocative ability, or the ability to make decisions based on changes that occur, is an acquired skill that is vital to farm success. The researchers showed that the economic performance of farmers improved after investments in education and extension were made to teach farmers how to respond to change. Because Huffman found little evidence that education alone will lead to an increase in production, he states that it is reasonable to assume that education helps farmers see changes occurring and adapt their behavior.

[8] The weak axiom of profit maximization is a premise that states that, to be a profit maximizing point, the profit from the choice made must be greater than or equal to the profit gained from other possible choices at that time.

Makinen (2013) used a structural equation model of management capacity and financial performance to analyze how managerial thinking and management process effectiveness affect profitability on the farm. Makinen writes that “managerial thinking relates to a farmer’s personal aspects: it is a question of how farmers think and position themselves as regards to business activities and decision making (p.454).” It is a reflection of the farmer’s goals, attitudes, and sense of control. Management process effectiveness refers to the activities that farmers undertake in decision making – planning, controlling, how they use information, and how they analyze decisions to be made. Makinen found that managerial thinking is connected to farm profitability, while management process effectiveness is not. However, management process effectiveness was clearly related to managerial thinking, meaning farmers with high levels of managerial thinking were also highly active in the management process. This leads to the conclusion that planning and controlling activities alone may not lead to financial success, but farmers who set goals, appreciate their professions, and have high levels of strategic thinking participate in planning and controlling activities and report higher financial performance.

Gloy and LaDue (2003) conducted a survey to evaluate the relationship between farm financial management practices and financial success on the farm. Survey questions covered topics including capital acquisition practices, business analysis techniques, and capital investment decision-making processes. Using a linear regression model, the greatest returns to these financial management practices came from the investment analysis and decision-making areas. The researchers found that, when manual calculations and decision-making processes were used, better financial performance was observed than when farmers did calculations “in their heads.”

Chavas and Aliber (1993) conducted a nonparametric analysis of technical, allocative, scale, and scope efficiencies[9] of agricultural production. The researchers found that economic losses on the farm were usually associated with allocative inefficiencies and scale inefficiencies. It was also noted that economies of scope tend to be large for small farms, compared with larger farms, implying that small farms see more benefits from having a diverse production plan. With no specialization to focus on, small farmers face a more dynamic growing season and decision-making is critical to optimize production.

Beginning farmers in particular may make farm decisions differently than established farmers, due to their unique situations and contexts. Rantamaki-Lahtinen and Vare (2012) found that beginning farmers in south-western Finland were more eager than established farmers to develop their farm, but only considered traditional methods, such as growing in size, to be helpful.

Decision-making and management practices are key factors in determining farm profitability. If more farmers learn the value of financial analysis, setting farm goals, and making management plans, it is possible that profitability of farms could increase. This study is based in the realm of farm decision making, being influenced by the effects that changes in a farmer's situation will have on the farmer's decision making. Knowing which qualities lead to strong decision making and which decisions are most important to beginning farmers are the backbone of this study.

[9] According to Chavas and Aliber (1993), technical efficiency refers to whether the farm is using the best available technology in its production process. Allocative efficiency, or price efficiency, represents the farm's ability to cost minimize when selecting inputs. Scale efficiency refers to the optimal size and output of the farm. Scope efficiency represents the farm's choices in terms of the number of different types of outputs it produces.

Summary

Multiple studies have been conducted in order to understand what differentiates beginning farmers from established farmers in character, situation, and how they make farm decisions. There has also been research on the factors that lead to beginning farm success. There are multiple ways to measure success on the farm: utility, costs, profits. Beginning farmers today are often balancing on- and off-farm labor in order to establish successful farms. This study makes an effort to include significant of on- and off-farm factors facing beginning farmers in order to more accurately model the decisions available to them in the formative years of their farm enterprises.

CHAPTER 3: METHODOLOGY

Introduction

In this chapter, linear programming is introduced as a method for developing an optimal farm plan and profit maximization theory is discussed, the empirical model and data used in the study are described, and model assumptions and limitations that affect the results obtained by this model are discussed.

The profit-maximizing model introduced in this chapter is designed to evaluate the consequences of labor management decisions on a Virginia vegetable farm. Information used in determining a labor management plan was based upon development of a baseline linear programming model of a Virginia vegetable farm, modeling alternatives to the baseline model, and analyzing the effects of changes made to variables within the model and alternative models. The model used in this study produces a farm plan which outlines labor allocation across the farm family, paid hired labor, acreage farmed, and total (on- and off-farm) profit during one year of farm operation.

The sub-objectives of this study are achieved by manipulating the model and variables included in the model. Payments made toward family debt, rent paid on farm land, and payments made for machinery were either increased or decreased to demonstrate variability across farm operations. The results of these changes are compared against the original model to observe how they affect the long-term profitability of the farm. Similarly, the effects of changes in on- and off-farm income and expenses, such as a raise in salary or increased input costs, on labor decisions are observed by comparing the labor allocation recommendations in the adjusted model with the original. Lastly, the total amount of time an individual is willing to work on- and off-farm, the amount of hired labor, and farm goals were adjusted to see how the total profit compared with the baseline model.

Linear Programming

Linear programming uses algorithms in the planning of activities to obtain an optimal result, that is, a result that reaches the specified goal best (according to the mathematical model) among all feasible alternatives (Hillier & Lieberman, 2010). The use of this type of planning began during World War II (WWII), when resources needed to be allocated efficiently across the various military operations. After WWII, the use of linear programming spread rapidly as businesses and other organizations recognized the similarities between their management needs and those of the military (Hillier & Lieberman, 2010).

The linear programming software used in this study is the General Algebraic Modeling System (GAMS). This software is designed for modeling linear and nonlinear optimization problems. The qualities of GAMS that influenced its use in this study include its easy-to-read algebraic statements, pinpointing of the location and type of errors that occur, and the ease of conducting a marginal analysis. A marginal analysis tells the user how much a change in data value will affect the optimal solution. The marginal analysis feature is useful in achieving the study objective of analyzing how changes in a variety of factors affect the long-term profitability of the farm. However, a marginal analysis is limited in that only small and independent changes can be analyzed. That is, the effect of a one unit change cannot be extended to reflect the effect of a 100 unit change.

Linear programming models are all written similarly. Hillier and Lieberman (2010) give a generic equation and restrictions:

$$\text{“Maximize } Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n \quad (1)$$

Subject to the restrictions

$$\mathrm{a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \leq b_1} \quad (2)$$

$$a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \leq b_2 \quad (3)$$

$$\vdots$$

$$a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \leq b_m \quad (4)$$

and

$$x_1 \geq 0, x_2 \geq 0, \cdots, x_n \geq 0 \text{ (p. 32)"} \quad (5)$$

where

"Z = value of overall measure of performance.

x_j = level of activity j (for j = 1, 2, …, n).

c_j = increase in Z that would result from each unit increase in level of activity j.

b_i = amount of resource i that is available for allocation to activities (for i = 1, 2, …, m).

a_{ij} = amount of resource i consumed by each unit of activity j (p. 31)."

Equation (1) is the objective function, and equations (2) through (5) are constraints. The variables x_1, x_2, …, x_n are decision making variables (DMVs).

All linear programming models are based on four mathematical assumptions. These assumptions are: proportionality, additivity, divisibility, and certainty. Hillier and Lieberman (2010) define each of the four assumptions as follows:

Proportionality: "The contribution of each activity to the value of the objective function Z is proportional to the level of the activity x_j, as represented by the c_jx_j term in the objective function. Similarly, the contribution of each activity to the left-hand side of each functional constraint is proportional to the level of the activity x_j, as represented by the $a_{ij}x_j$ term in the constraint. Consequently, this assumption rules out any exponent other than 1 for any variable in any term of any function (whether the objective function or the function on the left-hand side of a functional constraint) in a linear programming model." (p. 36)

Additivity: "Every function in a linear programming model (whether the objective function or the function on the left-hand side of a functional constraint) is the sum of the individual contributions of the respective activities." (p. 39)

Divisibility: "Decision variables in a linear programming model are allowed to have any values, including noninteger values, that satisfy the functional and nonnegativity constraints. Thus, these variables are not restricted to just integer values. Since each decision variable represents the level of some activity, it is being assumed that the activities can be run at fractional levels." (p. 41)

Certainty: "The value assigned to each parameter of a linear programming model is assumed to be a known constant." (p. 41)

If a problem violates any of these assumptions, linear programming will not be able to realistically represent it and a realistic optimal solution will not be found.

The model used in this study is a mixed-integer linear programming model. This involves problems in which only some of the variables are constrained to be integers, while other variables are allowed to be non-integers. This method was used to allow for the off-farm labor constraints to take on values of either zero or a range of integer values. This restriction is not used in general linear programming as it violates the divisibility assumption. This model is considered a mixed-integer model because the divisibility assumption holds for the rest of the variables.

Theoretical Framework

To better understand the development of this model, one must first understand the general profit-maximization model and how the program will find the optimal solution. The general profit function is given by equation (6). Profit, π, is determined by subtracting total costs, *C(q)*, from total revenue. Total revenue is represented by multiplying the quantity of goods produced, q, by price per unit, *p*.

$$\pi = pq - C(q) \qquad (6)$$

The linear programming software maximizes profit given the constraints laid out in the model. The profit function in equation (6) becomes the objective function in the model, represented by equation (7). Relationships among decision making variables in equation (7) are defined by constraints within the model. Constraints are composed of equalities and inequalities. An example of an equality constraint in a farm profit maximization problem may be that one acre of a crop demands a specific amount of labor hours. An example of an inequality constraint may be that the amount of land farmed must be less than or equal to the amount of land the farmer rents. Given the objective function and constraints, the linear programming software will find the optimal quantity, q, to maximize profits, π.

$$\text{Max } \pi = pq - C(q) \qquad (7)$$

Modeling Farm Profit

One economic assumption is that producers behave as profit maximizers. Under this assumption, farmers make operational decisions with the goal of earning the largest profit. There are alternative theories suggesting that farmers may not act as profit maximizers. Non-optimal behavior by farm owners can be explained by factoring in constraints faced and/or imposed by farmers, or by considering alternative behavioral and economic theories to profit maximization, such as farmers acting as satisficers, cost minimizers, or utility maximizers.

The most common factor that would lead to the conclusion that farmers are not profit maximizers is the exclusion of off-farm income in calculations of profit. Many farmers treat their farm and family income and expenses as one, working toward maximizing overall wealth rather than farm profit[10]. Chase and Lerohl (1981) pursued the idea that farm income is not the only measure of economic well-being for farmers. While this study did not actually measure economic well-being, it proposed a framework that would include on- and off-farm income, as well as assets. If farm and off-farm income and expenses were to be combined, it is possible that farmers are not profit maximizers but farm households are profit maximizing units.

Rather than profit maximizers, farmers may be either satisficers or cost minimizers. Tauer and Stefanides (1998) concluded that many farmers did not adjust their plans proactively. Rather, they waited until their current plans proved not to be optimal and then adjusted accordingly. In this way, farmers were acting as satisficers, as the farmers were settling for options that may not have been optimal but still addressed the problems they faced. This same study also concluded that some farmers were acting as cost minimizers. This is the assumption that producers make decisions based on which course of action has the lowest cost. Cost minimization does not factor in the amount of revenue that will be brought in by the chosen activities.

A third alternative to profit maximization is utility maximization. This is the assumption that farmers make choices in such a way that they obtain the highest possible level of satisfaction. Makinen (2013) found that one quality of successful farmers was a high

[10] According to the Encyclopedia Britannica, wealth is the measure of the monetary value of all assets. Income is the net total of the flow of payments received (Distribution of wealth and income, 2015).

appreciation of farming as an occupation. Many beginning farmers have higher levels of education (i.e. more years of schooling) than established farmers and, thus, would have higher returns to human capital from off-farm work (Mishra 2009). However, the ability to make more money off-farm does not influence the farmer's final decision, as the appreciation of farming itself may induce farmers to abandon profit maximization goals and choose to maximize individual utility and work on the farm.

As the decisions made by satisficers are unpredictable, cost minimization only focuses on one half of the farm financial picture (ignoring farm revenue), and individual utility cannot be easily measured or observed, the framework proposed by Chase and Lerohl (1981) to include on- and off-farm income in the measurement of farm wealth forms the base of this labor allocation study. However, their proposed framework was altered to exclude assets, as this study is concerned with inflows and outflows of money within the farm family, not overall worth. By including off-farm incomes and expenses but excluding assets, an altered profit maximization model was developed.

Little has been done in the field of modeling farm labor decisions to maximize total profitability. That is, several researchers have taken interest in the individual pieces on which this study was based, but no study exists to model on- and off-farm labor decisions for beginning farmers.

Tauer and Stefanides (1998) were interested in profit maximization, using the weak axiom of profit maximization to test how successful New York State dairy farms were at maximizing profit. A tobit regression was performed on the characteristics of the 70 farms in the study. Mishra and Moss (2013) focused on off-farm income, but studied the effect it has on farmland values, rather than farm household income. Like Tauer and Stefanides, Mishra and Moss used a regression analysis to examine past data without modeling future outcomes.

The model created for this study differs from existing models in that it factors in three important aspects. First, the model takes into account the importance of off-farm in measuring the profitability of a farm household. Second, this model is meant to predict future income and model farm decisions that have not yet been made, rather than analyze data from past seasons and report on past decisions. Third, this model was created to be a tool used by beginning farmers, in which an individual farm's data can be entered and unique farm plans produced.

Model Notation

A linear programming model is created using the mathematical optimization software, General Algebraic Modeling System (GAMS). This model maximizes total (i.e. on- and off-farm) profit (π) given farm and household constraints defined as a farm household who elect to produce vegetable crops. The decision making variables and constraints included in the model are farmer and farm information, and farm and family income and expenses.

$$Max\ \pi = \sum_{i=1}^{n} w_{oi} l_{oi} + \sum_{i=1}^{n} Y_i + \sum_{j=1}^{m} p_j q_j + S - LIV_n - R(AG) - D - w_f l_{fh} - h(INS) - \sum_{j=1}^{m} c_j q_j \quad (8)$$

Subject to:

$$\sum_{j=1}^{m} q_j = AC \quad (9)$$

$$AC \leq AG \quad (80)$$

$$l_{oi} + l_{fi} \leq G_i \quad (91)$$

$$l_{oi} \leq or = X_i, 0 \quad (102)$$

$$l_{fi} + l_h = \sum_{j=1}^{m} t_j \quad (113)$$

$$q_1 = q_2 = q_3 = \cdots = q_m \quad (124)$$

Where:

π = total (on- and off-farm) profit

i = subscript denoting family member i

n = total number of family members

w_{oi} = off-farm wage of individual i

l = hours of labor

Y_i = off-farm salary of individual i

j = subscript denoting crop j

m = total number of crops grown

p_j = revenue per acre of crop j

q_j = number of acres grown of crop j

S = family savings

LIV_n = living expenses for a family of size n

R = farm rent

D = annual family debt

w_f = wage paid to farm workers

h = hired labor

INS = insurance costs

c_j = costs per acre for crop j

AC = acres of land the family is currently planting

AG = acres of land the family wishes to farm in the long-run (and total acres of land rented)

G_i = number of hours individual i is willing to work per year

X_i = number of hours individual i is required to work off-farm per year

t_j = hours of labor required by crop j per year

Equation (8) represents the objective function that is maximized. Total revenue is comprised of variables related to income in the model, including: wage and salaried off-farm income ($w_{oi}l_{oi}$, Y_i), market price of vegetables common to Virginia farmers (p_j), and savings available (S) for the family to spend on home or farm expenses.

Total costs are comprised of variables related to farm and family expenses in the model, including: living expenses (LIV_n); farm rent (R); family debt (D); cost of farm labor, either as a wage for hired labor or opportunity cost for the farm family (w); insurance for family and farm workers (INS); and the cost of non-labor inputs (c_j).

Variables related to the farmer and farm family include: family size (n), hours each family member is willing to work (G_i), crop rotation, and farm goals in terms of size (AG) and types of produce grown. These factors are incorporated into the model as constraints to the profit maximizing equation.

Equations (9) through (14) list the constraints used in this model. Equations (9) and (10) are land constraints, which limit planted acreage to less than or equal to the farmer's available land. Equation (11) is a personal labor constraint, which limits an individual's on- and off-farm labor to the total hours he or she is willing to work per year, G_i. Equation (12) is a second labor constraint, which states that each individual must work up to or equal to the number of hours, X_i, required by his or her off-farm employer if the farmer has a wage position, and equal to X_i if the individual has a salaried position. In addition, each individual has the option to work zero hours off-farm, representing that he/she would quit the off-farm position. Equation (13) is a farm labor constraint, which states that the total hours that the family and hired workers spend on farm must equal the amount of labor, t, which the planted crops require. Equation (14) is a constraint used to represent crop rotation. By requiring all crops to be grown on the same total acreage, crop rotation in later years does not need to be specifically defined. That is, this model implements a crop rotation plan that, during a rotation, requires all vegetables of one category (leafy, fruiting, root, and legume) to be replaced with vegetables of another category. That is, all leafy vegetables would be replaced with fruiting vegetables, which are replaced with root vegetables, which are replaced with legumes, which are replaced with leafy vegetables. Using this method, each crop would change location when a cycle of the crop rotation is observed, but the total acreage would remain constant.

The last constraints included in the model but not listed in the model notation section include transfer equations and constraints that define values. Transfer equations are used to make the output of one equation useful in another. For example, one constraint within the model requires that the hired labor hours and on-farm labor hours of the farmer and spouse sum up to equal a variable, which represents the total labor hours used on the farm. This variable is then used in other constraints instead of listing each labor variable. This method is also used to define which vegetables are to be considered leafy, fruit, root, or leguminous vegetables. The final constraints used in the model are simple constraints which set fixed amounts for certain variables. This method is used to define the amount of savings and debt the family owes, the living expenses facing the family, and the "goal" acreage that the family wishes to plant in the long run.

Description of Data

The data in this study is collected from Virginia-specific sources when possible. Some variables used in this model were based on assumptions. Many of the variables, including family size, income and wages, living expenses, farm goals, land availability, rent price, crops grown, personal debt and savings, and off-farm income are all specific to the individual in question and can be adjusted in the model to reflect different family sizes, living arrangements, and personal situations. General estimates are made based on information about Virginia beginning vegetable farmers.

The family in this model consists of a farmer, spouse, and two children (n=4). This is chosen because the average family household size in the United States in 2015 was 3.14, which is rounded up to four total family members (U.S. Census Bureau, 2015). The goal farm size is set at 14 acres (AG=14). The 2012 U.S. Census of Agriculture reported vegetables harvested for sale were grown on 1,656 farms and 22,454 acres in Virginia (USDA NASS, 2014a). This represents an average of 13.56 acres (rounded up to 14 for simplicity in the model).

The family lives and farms in Blacksburg, VA. The annual living expenses are set at \$51,485 (LIV_n-51,485) based on the Massachusetts Institute of Technology Living Wage Calculator (Glasmeier, 2016). This total includes food, child care, medical, housing, transportation, and miscellaneous costs for a family of two adults (both working) and two children in the Blacksburg/Christiansburg/Radford area of Virginia. The farmer compensation is set with an hourly wage rate of \$15.05 ($w_{o1}=15.05$, $Y_1=0$), while the spouse is assigned a salary of \$48,992($w_{o1}=0$, $Y_1=48,992$), though the model is capable of calculating either waged or salaried income for either family member. In order to ensure that the spouse's wage is not added into the objective function if the spouse quit his/her off-farm position, the salary is made dependent on the spouse's off-farm work hours. The salary is converted into an hourly format - \$23.55 per hour, with the hours restricted to either full-time (2,080) or zero, as described below. These averages are based on hourly and salaried pay averages for individuals in the Blacksburg/Christiansburg/Radford area of Virginia with Bachelor of Science (B.S.) degrees ("Average Salary," 2016) and sourced from payscale.com. This education level is selected because beginning farmers tend to be more educated than established farmers (Rantamaki-Lahtinen & Vare, 2012; Mishra, et al., 2002). The farm family's annual debt payments and accumulated savings are set to zero (D=0; $S=0$), as these two values are variable and personal to each family and no averages could be obtained.

The farm family is assumed to grow a combination of leafy, fruit-bearing, root, and leguminous vegetables. The leafy vegetables are broccoli and sweet corn. The fruit-bearing vegetables are tomatoes and cucumbers. The root vegetables are onions and potatoes. Lastly, the leguminous vegetables are lima beans and snap beans. These vegetables were recommended for Virginia farmers by Virginia Cooperative Extension (VCE) (O'Dell & Relf, 2009).

Other variables in this study are based on Virginia or U.S. averages. Revenue per acre (p_j), costs per acre (c_j), and hours of labor required (t_j) for each crop are determined using enterprise budgets by Virginia Cooperative Extension and Pennsylvania State Extension (Orzolek, Bogash, Harsh, Kime, Harper, n.d.; Orzolek, Kime, Harsh, Harper, n.d.; VCE, 2014). The revenue, costs, and hours of labor required used in the model are listed in Table 5 below with a (V) or (P) indicating which state provided the information. While it is ideal to obtain pricing and cost information that is representative of all Virginia farmers, inaccurate information will not affect the functionality of the model, only the applicability of the results. The labor hours indicated for each crop are solely for the production of the crop. Farm families often spend time dedicated to farm finances, planning, or other out-of-field activities that are not factored into the labor costs of this model.

Table 5: Vegetable Revenue, Costs, and Labor Requirements Per Acre (Orzolek, Bogash, Harsh, Kime, Harper, n.d.; Orzolek, Kime, Harsh, Harper, n.d.; VCE, 2014)

Vegetable	Revenue per acre	Costs per acre	Labor Hours
Broccoli (V)[11]	$3,960.00	$3,007.40	64.06
Corn (V)	$2,664.00	$591.91	61.54
Tomato (P)	$5,000.00	$3,831.39	128.63
Cucumber (V)	$4,800.00	$2,969.13	249.93
Onion (P)	$10,500.00	$7,316.22	209.68
Potato (V)	$3,960.00	$1,743.03	29.82
Snap Bean (V)	$1,800.00	$1,437.09	16.15
Lima Bean (V)	$3,000.00	$2,313.00	122.74

The wage for farm workers is set to $9.30 per hour ($w_f$=9.30), based on the 2014 median pay of agricultural workers found by the U.S. Bureau of Labor Statistics (US DOL, 2016). Farm rent was set at $31 per acre per year ($R$ = 31), based on averages for non-irrigated cropland in Montgomery County, Virginia (Bruce & Groover, 2015).

The number of total hours each individual is willing to work was set to up to 12 hours per day. This number is found by subtracting eight hours for sleep, three hours for meals, and one hour for travel from a 24 hour day, and then multiplied by 365 days to obtain a total of 4,380 working hours ($G_i \leq 4,380$). This is an exaggerated statement of labor availability, which will allow for the adjustment of this value when running models. This model did not include labor available by the family's two children. The hours required to work by the farmer and spouse are

[11] A (V) denotes that the information was based on Virginia Cooperative Extension budgets, while a (P) denotes that the information was found with Pennsylvania State Extension budgets.

based on common work-week hours. The farmer, who works a waged job, is required to work either zero hours or at least 1,040 hours and no more than 2,080 (X_1=0, or 1,040 ≤ X_1 ≤ 2,080), based on a minimum of 20 hours and maximum of 40 hours a week for 52 weeks. The spouse, who holds a salaried position, is set to work either zero hours or exactly 2,080 hours (X_2=0 or 2,080).

Insurance for farm workers is required for all paid hired labor. The insurance costs are set to $4,126 per employee (*INS =4,126*(h/2080)*, based on Virginia averages by the Henry J. Kaiser Family Foundation (2014).

Model Assumptions

There are a number of critical assumptions that were made during the development of this model. The first assumption is that farmers act rationally to maximize profit. This means that the producer will continue to produce an additional unit of a good or service such that marginal revenues equal or exceed the marginal costs associated with producing that additional unit. Second, the model assumes that farmers have complete information and are aware of all costs and incomes that they face The model also assumes that the farmer is a price-taker acting within a perfectly competitive market structure, leaving the farmer unable to dictate or influence the price of the produce he/she sells. Lastly, in order to maximize profit, this model also assumes that there is demand in the market for all products that the farmer wishes to sell.

Many assumptions related to availability of inputs were made as to not constrain the model. This model assumes that there is an unlimited supply of farm workers available to hire each year at that wage and that this labor is available by the hour. That is, the farmer would be able to find hired labor whether they need only two hours of labor or 100 full-time employees. The farmer in the model is also assumed to have available equipment, eliminating the need for inclusion of the associated start-up costs in the model, and that any buildings will not need to be maintained or replaced. Lastly, the farmer is assumed to already rent an amount of land equal to his or her goal acreage.

CHAPTER 4: RESULTS

Introduction

The results of the mixed integer linear programming models are presented in this chapter. Specifically, this chapter includes results from models addressing:

- A baseline situation
- High acreage
- Limited willingness to work
- High labor costs
- Low off-farm wage
- High debt

Model: Baseline

The optimal results and marginal values associated with the baseline model, developed using the information defined in the previous chapter, are listed in Table 6. The baseline model revealed that the optimal solution is for the farmer and spouse each to work full-time positions (2,080 hours) off-farm. With the farmer working for $15.05 per hour and the spouse working for $23.55 per hour, a total of $80,288 in off-farm income is generated for the family. Regardless of whether the family decides to farm, they owe $51,485 in living expenses and $31 per acre of land rented. This totals to $51,919. The family earns an off-farm profit of $28,369. This model found that the family should farm, in addition to working off-farm. All 14 acres of land are planted, and requires 1,544.463 hours of labor. All farm labor is fulfilled by the farmer's spouse. This model assigned farm labor hours arbitrarily between the farmer and spouse. As the farm labor hours are in addition to off-farm labor hours, and total labor hours do not yet reach the given willingness to work constraint (4,380 hours per individual), it can be assumed that the farm labor hours may be redistributed between farmer and spouse without affecting the total profit. Farming all 14 acres of land without hiring labor earns the family $62,447 in farm revenue and cost $40,616.05. This equals a net $21,830.95 gain in farm profit. In total, this arrangement generates $50,199.95 of total (on- and off-farm) profit for the farm family.

In the baseline model, the marginal values indicate the benefit or cost to the farm family's profit (in dollars) should the constraints be loosened by a value of 1.0. If the farmer works one more hour off-farm, the objective function value increases by 15.05. The spouse's marginal value, $23.550, is misleading, as the spouse works a salaried position in this model and can either work zero hours or 2,080 hours – it is not possible to loosen this constraint in the way suggested by the marginal analysis. Acres of land planted has a marginal value of $1,528.354, indicating that acquiring and farming an additional acre of land increases total profit. Hired labor hours has a marginal value of -$11.28, signifying that hiring labor decreases total profit in the amount paid by the farmer to cover the wage and insurance costs. Increasing the farmer's and spouse's total willingness to work has no effect, as these are not limiting constraints in this model. In this situation, the farmer and spouse have an abundance of labor availability and high wages, allowing them to farm all 14 acres of their land without hiring labor or limiting off-farm work. In order to draw further conclusions about the farm family's decisions, the land availability, willingness to work, labor cost, and farm wage variables will be tested in the following models.

Table 6: Results and Marginal Analysis, Baseline Model

	Level	**Marginal**
Objective Function	$50,199.95	
Total Hours Willing (Farmer)	4,380	
Total Hours Willing (Spouse)	4,380	
Off-Farm Hours (Farmer)	2,080	15.050
Off-Farm Hours (Spouse)	2,080	23.550
Acres Planted	14	1,528.354

Hours Needed on Farm	1,544.463	
Farm Hours (Farmer)	0	
Farm Hours (Spouse)	1,544.463	
Hours Hired	0	-11.280

Model: High Acreage

Farmers have access to varied amounts of land. While some farmers may have access to hundreds of acres to farm, others may have less than ten. In the baseline model, the farm family has 14 acres of land available to farm. The farmer and spouse are easily able to work full-time jobs and work all 14 acres given their total willingness to work. The amount of land available to be planted, or goal amount, is changed to 1,000 acres to see how the farm plan and profitability changes if the farmer and spouse did not have enough work hours to plant it all.

The optimal results and marginal values associated with this model are listed in Table 7. The high acreage model reveals that the optimal solution is to plant all 1,000 acres. The farmer and spouse continue working full-time off-farm and all remaining work hours are spent on the farm. Additional labor is hired to meet the labor requirements. This farm plan generates $364,649.25 in total (on- and off-farm) profit for the farm family.

In this high acreage model, the marginal values of the farmer's and spouse's willingness to work is $11.280, as working one more hour allows the farmer or spouse to displace one hour of hired labor and the costs of that labor decreases. The marginal values associated with the farmer's and spouse's off-farm work are irrelevant because they would not work more than a full-time (2,080 hour) position. The marginal value of acres planted has a value of $283.958, indicating that acquiring and farming an additional acre of land increases profit. Lastly, the marginal values of the farmer's and spouse's on-farm hours are negative but equal in magnitude to the off-farm work hours, as working on additional hour on-farm increases the objective function by the value of one hour of displaced hired labor but decreases it by one hour's worth of off-farm wages.

This model shows that it is more profitable for farmers to work on- and off-farm as much as possible before deciding to hire labor. However, hired labor is necessary to maximize profit by planting all of the acreage available.

Table 7: Results and Marginal Analysis: High Acreage Model

	Level	Marginal
Objective Function	$364,649.25	
Total Hours Willing (Farmer)	4,380	11.280
Total Hours Willing (Spouse)	4,380	11.280
Off-Farm Hours (Farmer)	2,080	3.770
Off-Farm Hours (Spouse)	2,080	12.270
Acres Planted	1,000	283.958
Hours Needed on Farm	110,320	
Farm Hours (Farmer)	2,300	-3.77
Farm Hours (Spouse)	2,300	-12.27
Hours Hired	105,720	

Model: Limited Willingness

In the baseline model, the farmer's and spouse's willingness to work was set to 4,380 hours. This is a large percentage of the individual's time, and it is likely that not every beginning farmer is willing to spend every waking hour either eating or working. For this reason, the farmer's willingness to work is set at a part-time level (1,040 hours), while the spouse's willingness to work is set to a full-time level (2,080). These values are selected as they represent the minimum off-farm work requirements for each individual, leading to a choice between working off-farm and quitting to work on-farm. All other variables and constraints remain identical to the baseline model.

The optimal results and marginal values associated with the limited willingness model are listed in Table 8. This model found that the optimal solution is for the farmer and spouse to spend all working hours off-farm. The same acreage and work requirements are required as in the baseline model, however, all labor is hired in this model. This arrangement generates $17,126.42 in total (on- and off-farm) profit for the farm family.

The marginal values associated with the farmer's and spouse's willingness to work remain identical to those in the baseline model. The marginal value for acres planted is identical to that in the High Acreage model. For on-farm work hours, the farmer and spouse both have negative marginal values, indicating that profits are negatively impacted if either individual was to work on-farm.

This model shows that it is more profitable for the farmer and spouse to both work off-farm instead of farming and to hire labor to work on the farm. It is not possible to know from the results of this model whether this is because the off-farm job is more profitable than farming, if a low labor cost makes it possible to hire labor on the farm and continue working off-farm, or a combination of both. The following two models address these two scenarios.

Table 8: Results and Marginal Analysis, Limited Willingness Model

	Level	Marginal
Objective Function	$17,126.42	
Total Hours Willing (Farmer)	1,040	15.050
Total Hours Willing (Spouse)	2,080	23.550
Off-Farm Hours (Farmer)	1,040	
Off-Farm Hours (Spouse)	2,080	
Acres Planted	14	238.958
Hours Needed on Farm	1,544.463	
Farm Hours (Farmer)	0	-3.770
Farm Hours (Spouse)	0	-12.270
Hours Hired	1,544.46	

Model: Limited Willingness with High Labor Costs

Given the current limited availability of agricultural labor force in the U.S., hiring labor is not always an option for farmers. While the baseline model uses the average hourly wage of farm workers, it is important to understand how decisions are made when labor costs become too great. In this model, labor costs are increased to $1,000 per hour, while all other variables and constraints remain identical to the “Limited Willingness” model. The “Limited Willingness” model is used over the baseline model due to the fact that the baseline model’s indicated optimum did not rely on hired labor.

The optimal results and marginal values associated with the limited willingness and high labor costs model are listed in Table 9. Should labor costs become too great, it becomes optimal for the farm family not to farm at all and to spend all work hours off-farm. This situation generates $12,717.00 in total (on- and off-farm) profit. The marginal values for the farmer’s and spouse’s willingness to work are identical to the baseline model. The marginal values of the acres planted and farmer’s, spouse’s and hired labor hours all indicate that the total profit decreases should the family decide to farm.

This model makes it apparent that the farmer and spouse in the “Limited Willingness” model made the decisions that they did because of the low labor cost. Rather than quitting either of their jobs and taking over the farm work themselves, the farmer and spouse are better off not farming at all.

Table 9: Results and Marginal Analysis, Limited Willingness/High Labor Model

	Level	**Marginal**
Objective Function	$12,717.00	
Total Hours Willing (Farmer)	1,040	15.050
Total Hours Willing (Spouse)	2,080	23.550
Off-Farm Hours (Farmer)	1,040	
Off-Farm Hours (Spouse)	2,080	
Acres Planted	0	-31.000
Hours Needed on Farm	0	
Farm Hours (Farmer)	0	-0.915
Farm Hours (Spouse)	0	-9.415
Hours Hired	0	-987.845

Model: Limited Willingness with Low Pay

In the previous models, it is clear that the farmer's off-farm job is more profitable than working on the farm. When given the choice between working the minimum number of off-farm hours and working on the farm in the last two models, the off-farm job remains optimal. For this reason, the farmer's off-farm wage is lowered to $0.01 per hour to see if having a low paying off-farm job causes the farmer to choose on-farm work. While this is an exaggeratedly low and unrealistic off-farm wage, it negates the need to define what is considered to be a "low" wage. All other variables and constraints remain identical to the "Limited Willingness" model. The "Limited Willingness" model is used over the baseline model due to the fact that the baseline model's indicated optimum did not require a choice between on- and off-farm labor.

The optimal results and marginal values associated with the limited willingness and low pay model are listed in Table 10. According to this model, it is optimal for the farmer's spouse to continue working off-farm while the farmer works on-farm. The same acreage and work requirements are required as in the "Limited Willingness" model, though only 504.463 hours of labor are hired, with the farmer covering the other 1,040 hours. This scenario generates $13,205.62 in total (on- and off-farm) profit.

The marginal value of the farmer's willingness to work is lower than in the "Limited Willingness" model, as this number is identical to the farmer's off-farm wage in the previous model and is now associated with the cost of displacing one hour of hired labor. If the farmer could work one more hour on the farm, total farm profit increases by $11.280. However, working one hour off-farm decreases profit by $11.270 (the value of the farmer's hour of labor on the farm minus the $0.01 wage rate). The marginal value of acres planted and spouse's on-farm work are identical to the Limited Willingness model. This model shows that, if off-farm wages are lower than total revenue earned for an hour on the farm, the individual would choose to farm.

Table 10: Results and Marginal Analysis, Limited/Low Pay Model

	Level	Marginal
Objective Function	$13,205.62	
Total Hours Willing (Farmer)	1,040	11.280
Total Hours Willing (Spouse)	2,080	23.550
Off-Farm Hours (Farmer)	0	-11.270
Off-Farm Hours (Spouse)	2,080	
Acres Planted	14	283.958
Hours Needed on Farm	1,544.463	
Farm Hours (Farmer)	1,040	
Farm Hours (Spouse)	0	-12.270
Hours Hired	504.463	

Model: Limited Willingness with High Debt

The previous models all assume that the farm family had no debt payments to make. However, debt payments are a reality for many farmers in Virginia. For this reason, the debt payments are increased by a large amount, $100,000, to illustrate how high debt impacts the profitability of the farm.

The optimal results and marginal values associated with the limited willingness with high debt model are listed in Table 11. In this situation, the farmer and spouse continue to work as many hours off-farm as possible, a scenario proven more profitable than on-farm work in the previous models. All 14 acres of land are planted, and hired labor used to meet the labor requirements. This scenario would cost the family $82,873.58 in total (on- and off-farm) losses. The marginal values associated with the farmer's and spouse's willingness to work and acres planted are identical to the "Limited Willingness" model.

This model illustrated that, because the labor cost in the previous models was low enough that hiring farm labor was still profitable, the farm family has an incentive to hire labor and produce crops on the farm in the face of high debt, even if total profit is still negative. Based on earlier models, it may be assumed that, given high debt and high labor costs, the farm family chooses not to farm at all and continues working the more profitable off-farm positions.

Table 11: Results and Marginal Analysis, Limited/High Debt Model

	Level	Marginal
Objective Function	-$82,873.58	
Total Hours Willing (Farmer)	1,040	15.050
Total Hours Willing (Spouse)	2,080	23.550
Off-Farm Hours (Farmer)	1,040	
Off-Farm Hours (Spouse)	2,080	
Acres Planted	14	283.958
Hours Needed on Farm	1,544.463	
Farm Hours (Farmer)	0	-3.770
Farm Hours (Spouse)	0	-12.270
Hours Hired	1,544.463	

Summary

The results of the mixed integer linear programming models lead to several conclusions. Based on the results of the baseline model, if a farmer and/or spouse are willing to dedicate a great amount of time to working, it is optimal for the individuals to work full-time and farm all available land on the side. The high acreage model shows that, if the farm family has more land than they can work alone, it is optimal to work as many hours on- and off-farm as possible and hire what is needed to farm the rest of the land. The limited willingness model illustrates that, in the absence of this excessive willingness to work, it is more profitable for the farmer and spouse to spend all labor hours off-farm and to farm all available land with the help of hired labor. This situation could be optimal either because hired labor is considered to be cheap or because the farmer's and spouse's off-farm jobs are more profitable. The limited willingness with high labor costs model makes it apparent that, when hired labor is too costly, it is optimal for the farmer and spouse to work their most profitable jobs – in this case, off-farm positions. However, the limited willingness with low pay model illustrates that there is a point at which farming may be more profitable than working off-farm and leads the farmer to quit his/her off-farm position and work only on the farm. The limited willingness with high debt model shows that, in the presence of high debt payments and low labor costs, it is more profitable to hire labor and earn as much revenue as possible, even if total profit is still negative. While these conclusions do not present any information that goes against logical reasoning, the purpose of this study was not to illustrate unknown scenarios; rather, to create a model that represents real-life labor decisions. In sum, the conclusions drawn by these models serve as confirmation of a sound representation of a profit maximizing farmer’s decision-making logic within the models.

CHAPTER 5: CONCLUSION

Study Summary

Beginning farmers face a number of challenges, including access to capital, land, and credit; finding profitable markets; education and training; and business planning and management. While there are numerous training programs offered to address these issues, these farmers continue to struggle (Niewolny & Lillard, 2010). Operating a farm requires strong decision-making skills that are often informed by past experiences. For farmers, daily decisions may pertain to land and equipment purchases, production plans, labor allocation, or more. A number of factors will determine what the "right" decision for a farmer is, and few tools exist that allow individuals to tangibly manipulate farm and personal information to estimate the effects a given change may have on profitability. This study aimed to address the need for a tool that will aid beginning vegetable farmers in making labor allocation decisions.

The results of the models developed in this study are only significant to the degree that the underlying assumptions that farmers act rationally to maximize profit occur in real-time decision-making. Alternatives to profit maximization were already discussed in Chapter 3. The assumption that farmers have complete information about the incomes and costs they face relates to the accuracy of the model's results, but does not influence the functionality of the model. The assumptions that there is sufficient demand in the market for all products that the farmer wishes to sell, that the products sold will not flood the market and cause a drop in price, and that the farm family already rents the land and equipment necessary to farm were all addressed in Chapter 2, where a lack of profitable markets, access to capital, access to land, and access to credit were stated as significant obstacles for farmers. Lastly, the assumption that there is an unlimited supply of farm workers is not found to be consistent in reality, as labor shortages are a growing problem for American farmers.

Conclusions and Implications

Using a tool such as that developed in this study may improve profitability of small, beginning farms in Virginia by providing a means for farmers to map out the consequences of various farm decisions and changes. The model developed in this study may be used to plan multiple years of farm development by running the model given anticipated changes. If no changes are made to income, living expenses, willingness to work, or other variables in the model, it is safe to assume that profitability on the farm will not change from year to year. However, if an individual expects changes in the coming years (e.g. change in income, lower or higher willingness to work, increased family size and living expenses, changes in prices, different crops grown), these changes can be entered into the model to view the effect they would have on the family's total (on- and off-farm) profitability. If beginning farmers were to use this planning tool, it is likely that farm viability would improve and failure rates for beginning farmers in Virginia would decrease, as more farmers are learning which decisions are optimal for their families given their specific situations.

Addressing farm growth planning could also be useful to established farmers and farm educators. Rantamaki-Lahtinen and Vare (2012) found that established farmers often had no development plans, instead repeating production cycles and habits year-to-year. A similar conclusion was drawn by Tauer and Stefanides (1998), who found that farmers were satisficing, rather than maximizing profit. They observed that farmers often did not change behavior and planning until they saw that the current activity was not optimal. However, by the time a plan is recognized as not profitable, it is sometimes too late for the farm to react. Based on Tauer and

Stefanides' findings, a proactive approach to farm planning is the key to success in established farms, with the planning of production and labor being one piece of the larger planning picture.

Lastly, farm educators may share the conclusions drawn in this study with beginning farmers. Dollisso and Martin (1999) concluded that farmers are most motivated by their desire to increase profitability, which will be the main framework used by this study. Goodwin and Schroeder (1994) found that beginning farmers are more likely to participate in educational programs than experienced farmers. Experienced farmers may feel they have nothing left to learn, or that their enterprises are running well enough under current management practices. If increasing profit is the main driving factor, it is possible that established farmers feel their operations are already maximizing profit. However, natural and economic environments are dynamic, and the farmers who produce within these environments must be ready to make changes at any time. Educators can teach farmers to see farm planning is an ongoing process and establish positive labor and resource allocation practices among the next and future generations of farmers.

Model Limitations

This study was limited by the nature of the data, the type of model used, and the agricultural industry. Information found through the secondary sources mentioned included averages from across counties, states, regions, or the country, which may not accurately represent individual circumstances. Other information used included assumptions based on averages. Using information from such a broad range of sources may skew the model such that it does not represent the average Virginia vegetable farmer. However, once a farmer puts in his or her personal information, this limitation will no longer apply, as the output is adjusted to fit his/her individual situation.

In general, linear programming models are limited as estimates are generated on what will happen in the future based on information entered in the present. If prices, policies, or other factors change in the time that the model represents, the results will no longer be accurate. However, the parameters in the model may be updated as these factors change over time. In addition, if the information entered into the model is incorrect, the output will not be accurate. Estimates made by this model will only be useful to Virginia's farmers if the information factored into the model is accurate. Lastly, linear programming models are limited by the four assumptions of linear programming: proportionality, additivity, divisibility, and certainty, as discussed earlier in this chapter.

Other limitations facing this study are due to the fact that agriculture is variable in nature. This is directly related to the assumption of certainty within a linear programming model. One main limitation is the seasonality of growing vegetable crops. Unless a farmer has a greenhouse, and sometimes even then, farmers will grow different crops during different times of the year as the seasons change. These planting changes will affect labor requirements through the year, crop yield, and market price of produce. This model was created on an annual scale, so the seasonality of crops is not visible in the results. Another important variable in agriculture is weather. Crop yield is strongly affected by weather changes each season. While farmers may invest in crop insurance, it is important to note that crop yield is variable and a linear programming model will not be able to accurately predict these weather-related changes. However, performing a sensitivity analysis on the model can address this variability by generating profit change information as prices and quantities produced change.

Lastly, this study is limited in that, in order to be impactful, beginning farmers must be aware of and choose to use this tool when making labor-related decisions on their farms.

However, as a GAMS program, the models used in this study do not have a user-friendly interface that would be widely accepted across Virginia. It is beyond the scope of this study to produce a tool with a user-friendly interface, though the framework developed in this study may be used to structure the development of future labor allocation tools.

Recommendations for Future Work

While this model uses sound decision-making logic to represent the effects of farm and family changes, there is room for growth within the model. More dynamic information processing and a user-friendly interface would strengthen the results of and increase the practicality of the tool. Some of the limitations of the model and recommended solutions are listed below.

- The model developed in this study has a simple breakdown of the cost of hired labor. The model requires the farm family to pay insurance costs for all employees working on the farm. However, the Affordable Care Act (sometimes called the ACA, or "Obamacare") does not require employers to pay for employee health insurance until 50 or more full-time employees are hired. This would require constraints in the model that were co-dependent and would necessitate the use of a non-linear programming model. In addition, the model pays a per-hour cost for employee health insurance, which does not accurately reflect the lump sum payment that must be made when contributing toward employee health insurance. Lastly, the model does not take into account the amount paid towards Social Security and other costs directly related to the wages paid for employees.
- This model does not include the option for the farm family's children (or other household members) to work on the farm. These family members would be included in the same way the farmer and farmer's spouse were included – they would not receive a wage in the

objective function, but would displace hired labor and decrease the total amount of money leaving the farm as farm wages.

- The out-of-field labor requirements of the farm family were not included in this model but could be added to more accurately reflect the time commitment a family makes when deciding to farm.
- The model developed in this study was on an annual scale. Farming is a seasonal profession and one piece of land may see several crops planted (known as "double cropping") over the course of one year. Modifying this model to represent a seasonal scale would allow for more specific and dynamic results.
- The model assumes that the farm land rented is non-irrigated. Including rent prices for irrigated land and the costs of irrigation would allow this model to be used by more individuals.
- Start-up costs (e.g. purchase of land or machinery) are not factored into this model. There is a variable for debt owed by the farm family in a lump sum. Adding start-up costs and interest rates on debt would allow for a more accurate representation of the family's debt to be paid.
- This model requires the farmer to grow eight specific vegetables. A future version of this model may allow for more or fewer crop and animal choices, depending on the farmer's preference. The model could also be expanded to include more crop rotation options.

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APPENDIX A: GAMS VARIABLE DESCRIPTIONS

DMV	Description
Z	Objective function value: The total (on- and off-farm) profit that the family will earn
LO1	Off-farm labor for farmer: The number of hours the farmer works at the off-farm job per year
LO2	Off-farm labor for spouse: The number of hours the spouse works at the off-farm job per year
LIV	Living expenses: The amount of money the family requires in living expenses per year
D	Debt: The amount of money the family owes in annual payments towards debt
LF	Hired labor: The number of hours of labor the family hires on the farm per year
LF1	On-farm labor for farmer: The number of hours the farmer works on the farm per year
LF2	On-farm labor for spouse: The number of hours the spouse works on the farm per year
TOTL	Labor requirements: The number of labor hours required by the farm crops per year
AG	Total land: The number of acres of land the family has available to plant
AC	Current land: The number of acres of land the family has planted in one year
S	Savings: The amount of money the family has saved
LE	Leafy vegetables: The number of acres planted with broccoli and corn
FR	Fruiting vegetables: The number of acres planted with tomato and cucumber
RT	Root vegetables: The number of acres planted with onion and potato
LEG	Legumes: The number of acres planted with lima beans and snap beans
BR	Broccoli: The number of acres planted with broccoli
CN	Corn: The number of acres planted with corn
TM	Tomato: The number of acres planted with tomato
CC	Cucumber: The number of acres planted with cucumber
ON	Onion: The number of acres planted with onion
PT	Potato: The number of acres planted with potato
SB	Snap beans: The number of acres planted with snap beans
LB	Lima beans: The number of acres planted with lima beans

APPENDIX B: GAMS EQUATION DESCRIPTIONS

Equation	Description
SEMICONT VARIABLE LO1	Off-farm labor constraint for farmer: States that farmer may work either 0 or between 1040 and 2080 hours at the off-farm job per year
SEMICONT VARIABLE LO2	Off-farm labor constraint for spouse: States that spouse may work either 0 or 2080 hours at the off-farm job per year
OBJ	Objective function: States the total (on- and off-farm) profit that will be made by the family per year
LAB1	Labor constraint for farmer: States the total hours the farmer is willing to work per year, on- and off-farm
LAB2	Labor constraint for spouse: States the total hours the spouse is willing to work per year, on- and off-farm
SAV	Savings: Defines the amount of money the family has saved
LIVEXP	Living Expenses: Defines the amount of money the family needs for a year of living expenses
DEBT	Debt: Defines the amount of money the family owes in debt payments in one year
LABHIRTOT	Labor constraint: States that the on-farm labor performed by the farmer and spouse, combined with the amount of labor hired, must equal the amount of labor needed to tend the farm's crops for one year
LABTOT	Total labor requirements: Defines the total hours of labor needed for all crops on the farm per year
GOAL	Total land: Defines the number of acres the family has available to farm
CURLIM	Land constraint: States that the number of acres currently planted cannot be greater than the amount of land available to farm
CURRENT	Current land: Defines the number of acres needed for the crops grown
LEAF	Leafy vegetables: States that broccoli and corn are leafy vegetables
FRUIT	Fruiting vegetables: States that tomato and cucumber are fruiting vegetables
ROOT	Root vegetables: States that onion and potatoes are root vegetables
LEGUME	Legumes: States that snap beans and lima beans are legumes

EQ1	Crop rotation: States that leafy and fruiting vegetables must be grown on the same total acreage
EQ2	Crop rotation: States that leafy and root vegetables must be grown on the same total acreage
EQ3	Crop rotation: States that leafy vegetables and legumes must be grown on the same total acreage
EQ4	Crop rotation: States that broccoli and corn must be grown on the same total acreage
EQ5	Crop rotation: States that tomato and cucumber must be grown on the same total acreage
EQ6	Crop rotation: States that onion and potato must be grown on the same total acreage
EQ7	Crop rotation: States that snap beans and lima beans must be grown on the same total acreage

APPENDIX C: GAMS MODEL: BASELINE

GAMS Rev 227 x86_64/MS Windows
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
C o m p i l a t i o n

```
option sysout=off;

VARIABLES
Z
LO1
LO2
LIV
D
LF
LF1
LF2
TOTL
AG
AC
S
LE
FR
RT
LEG
BR
CN
TM
CC
ON
PT
SB
LB;

POSITIVE VARIABLE
LIV
D
LF
LF1
LF2
TOTL
AG
AC
S
LE
```

APPENDIC C Cont.

```
FR
RT
LEG
BR
CN
TM
CC
ON
PT
SB
LB
;

SEMICONT VARIABLE LO1;
LO1.lo=1040;LO1.up=2080;

SEMICONT VARIABLE LO2;
LO2.lo=2079.99;LO2.up=2080;

EQUATIONS
OBJ
LAB1
LAB2
SAV
LIVEXP
DEBT
LABHIRTOT
LABTOT
GOAL
CURLIM
CURRENT
LEAF
FRUIT
ROOT
LEGUME
EQ1
EQ2
EQ3
EQ4
EQ5
EQ6
EQ7;

OBJ.. Z=E=(15.05*LO1)+(0*LO1)+(0*LO2)+(23.55*LO2)+S+(3960*BR)+(2664*CN)+(5
```

APPENDIC C Cont.

```
000*TM)+(4800*CC)+(10500*ON)+(3960*PT)+(1800*SB)+(3000*LB)-LIV-(31*AG)-D-(
9.3*LF)-(1.98*LF)-(3007.4*BR)-(591.91*CN)-(3831.39*TM)-(2969.13*CC)-(7316.
22*ON)-(1743.03*PT)-(1437.09*SB)-(2313*LB);
LAB1.. LO1+LF1=L=4380;
LAB2.. LO2+LF2=L=4380;
SAV.. S=E=0;
LIVEXP.. LIV=E=51485;
DEBT.. D=E=0;
LABHIRTOT.. TOTL-LF-LF1-LF2=E=0;
LABTOT.. TOTL-(64.06*BR)-(61.54*CN)-(128.63*TM)-(249.93*CC)-(209.68*ON)-(2
9.82*PT)-(16.15*SB)-(122.74*LB)=E=0;
GOAL.. AG=E=14;
CURLIM.. AG-AC=G=0;
CURRENT.. AC-BR-CN-TM-CC-ON-PT-SB-LB=E=0;
LEAF.. LE-BR-CN=E=0;
FRUIT.. FR-TM-CC=E=0;
ROOT.. RT-ON-PT=E=0;
LEGUME.. LEG-SB-LB=E=0;
EQ1.. LE-FR=E=0;
EQ2.. LE-RT=E=0;
EQ3.. LE-LEG=E=0;
EQ4.. BR-CN=E=0;
EQ5.. TM-CC=E=0;
EQ6.. ON-PT=E=0;
EQ7.. SB-LB=E=0;





OPTION limcol=0;
MODEL transitionone /all/;
SOLVE transitionone using mip maximizing Z;
```

COMPILATION TIME = 0.000 SECONDS 2 Mb WEX227-227 May 8, 2008

APPENDIC C Cont.

GAMS Rev 227 x86_64/MS Windows
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Equation Listing   SOLVE transitionone Using MIP From line 112

---- OBJ =E=

OBJ.. Z - 15.05*LO1 - 23.55*LO2 + LIV + D + 11.28*LF + 31*AG - S - 952.6*BR

- 2072.09*CN - 1168.61*TM - 1830.87*CC - 3183.78*ON - 2216.97*PT

- 362.91*SB - 687*LB =E= 0 ; (LHS = 0)

---- LAB1 =L=

LAB1.. LO1 + LF1 =L= 4380 ; (LHS = 0)

---- LAB2 =L=

LAB2.. LO2 + LF2 =L= 4380 ; (LHS = 0)

---- SAV =E=

SAV.. S =E= 0 ; (LHS = 0)

---- LIVEXP =E=

LIVEXP.. LIV =E= 51485 ; (LHS = 0, INFES = 51485 ****)

---- DEBT =E=

DEBT.. D =E= 0 ; (LHS = 0)

---- LABHIRTOT =E=

LABHIRTOT.. - LF - LF1 - LF2 + TOTL =E= 0 ; (LHS = 0)

APPENDIC C Cont.

---- LABTOT =E=

LABTOT.. TOTL - 64.06*BR - 61.54*CN - 128.63*TM - 249.93*CC - 209.68*ON

- 29.82*PT - 16.15*SB - 122.74*LB =E= 0 ; (LHS = 0)

---- GOAL =E=

GOAL.. AG =E= 14 ; (LHS = 0, INFES = 14 ****)

---- CURLIM =G=

CURLIM.. AG - AC =G= 0 ; (LHS = 0)

---- CURRENT =E=

CURRENT.. AC - BR - CN - TM - CC - ON - PT - SB - LB =E= 0 ; (LHS = 0)

---- LEAF =E=

LEAF.. LE - BR - CN =E= 0 ; (LHS = 0)

---- FRUIT =E=

FRUIT.. FR - TM - CC =E= 0 ; (LHS = 0)

---- ROOT =E=

ROOT.. RT - ON - PT =E= 0 ; (LHS = 0)

---- LEGUME =E=

LEGUME.. LEG - SB - LB =E= 0 ; (LHS = 0)

---- EQ1 =E=

APPENDIC C Cont.

EQ1.. LE - FR =E= 0 ; (LHS = 0)

---- EQ2 =E=

EQ2.. LE - RT =E= 0 ; (LHS = 0)

---- EQ3 =E=

EQ3.. LE - LEG =E= 0 ; (LHS = 0)

---- EQ4 =E=

EQ4.. BR - CN =E= 0 ; (LHS = 0)

---- EQ5 =E=

EQ5.. TM - CC =E= 0 ; (LHS = 0)

---- EQ6 =E=

EQ6.. ON - PT =E= 0 ; (LHS = 0)

---- EQ7 =E=

EQ7.. SB - LB =E= 0 ; (LHS = 0)

APPENDIC C Cont.

GAMS Rev 227 x86_64/MS Windows
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Model Statistics   SOLVE transitionone Using MIP From line 112

MODEL STATISTICS

BLOCKS OF EQUATIONS	22	SINGLE EQUATIONS	22
BLOCKS OF VARIABLES	24	SINGLE VARIABLES	24
NON ZERO ELEMENTS	74	DISCRETE VARIABLES	2

GENERATION TIME = 0.015 SECONDS 3 Mb WEX227-227 May 8, 2008

EXECUTION TIME = 0.015 SECONDS 3 Mb WEX227-227 May 8, 2008

APPENDIC C Cont.

GAMS Rev 227 x86_64/MS Windows
G e n e r a l A l g e b r a i c M o d e l i n g S y s t e m
Solution Report SOLVE transitionone Using MIP From line 112

S O L V E S U M M A R Y

MODEL transitionone OBJECTIVE Z
TYPE MIP DIRECTION MAXIMIZE
SOLVER CPLEX FROM LINE 112

**** SOLVER STATUS 1 NORMAL COMPLETION
**** MODEL STATUS 1 OPTIMAL
**** OBJECTIVE VALUE 50199.9525

RESOURCE USAGE, LIMIT 0.034 1000.000
ITERATION COUNT, LIMIT 0 10000

ILOG CPLEX May 1, 2008 22.7.2 WEX 4792.4799 WEI x86_64/MS Windows
Cplex 11.0.1, GAMS Link 34

Proven optimal solution.

MIP Solution: 50199.952500 (0 iterations, 0 nodes)
Final Solve: 50199.952500 (0 iterations)

Best possible: 50199.952500
Absolute gap: 0.000000
Relative gap: 0.000000

	LOWER	LEVEL	UPPER	MARGINAL
---- EQU OBJ	.	.	.	1.000
---- EQU LAB1	-INF	2080.000	4380.000	.
---- EQU LAB2	-INF	3624.463	4380.000	.
---- EQU SAV	.	.	.	1.000
---- EQU LIVEXP	51485.000	51485.000	51485.000	-1.000
---- EQU DEBT	.	.	.	.
---- EQU LABHIRTOT	.	.	.	EPS
---- EQU LABTOT	.	.	.	EPS
---- EQU GOAL	14.000	14.000	14.000	1528.354
---- EQU CURLIM	.	.	+INF	-1559.354
---- EQU CURRENT	.	.	.	-1559.354
---- EQU LEAF	.	.	.	47.009

APPENDIC C Cont.

---- EQU FRUIT	.	.	.	59.614
---- EQU ROOT	.	.	.	-1141.021
---- EQU LEGUME	.	.	.	1034.399
---- EQU EQ1	.	.	.	59.614
---- EQU EQ2	.	.	.	-1141.021
---- EQU EQ3	.	.	.	1034.399
---- EQU EQ4	.	.	.	-559.745
---- EQU EQ5	.	.	.	-331.130
---- EQU EQ6	.	.	.	483.405
---- EQU EQ7	.	.	.	-162.045

	LOWER	LEVEL	UPPER	MARGINAL
---- VAR Z	-INF	50199.953	+INF	.
---- VAR LO1	1040.000	2080.000	2080.000	15.050
---- VAR LO2	2079.990	2080.000	2080.000	23.550
---- VAR LIV	.	51485.000	+INF	.
---- VAR D	.	.	+INF	-1.000
---- VAR LF	.	.	+INF	-11.280
---- VAR LF1	.	.	+INF	EPS
---- VAR LF2	.	1544.463	+INF	.
---- VAR TOTL	.	1544.463	+INF	.
---- VAR AG	.	14.000	+INF	.
---- VAR AC	.	14.000	+INF	.
---- VAR S	.	.	+INF	.
---- VAR LE	.	3.500	+INF	.
---- VAR FR	.	3.500	+INF	.
---- VAR RT	.	3.500	+INF	.
---- VAR LEG	.	3.500	+INF	.
---- VAR BR	.	1.750	+INF	.
---- VAR CN	.	1.750	+INF	.
---- VAR TM	.	1.750	+INF	.
---- VAR CC	.	1.750	+INF	.
---- VAR ON	.	1.750	+INF	.
---- VAR PT	.	1.750	+INF	.
---- VAR SB	.	1.750	+INF	.
---- VAR LB	.	1.750	+INF	.

**** REPORT SUMMARY : 0 NONOPT
0 INFEASIBLE
0 UNBOUNDED

EXECUTION TIME = 0.000 SECONDS 2 Mb WEX227-227 May 8, 2008