DO OPERATORS LEVERAGE THEIR LABOR BY HIRING WORKERS? EVIDENCE FROM DAIRY FARMS

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ABSTRACT

When firms expand their business they typically hire more labor and in the process generate increased returns to the business owners. Similar to the concept of financial leverage, we define the degree of labor leverage to be the worker-operator ratio and empirically explore the relationship between the degree of labor leverage and the return to operator's labor and management using a dataset of closely held family dairy farms in New York State. Total return to operator labor is derived as a common return to generic operator labor and a supplemental return dependent upon managerial quality. The common return is estimated from an average production function with supplemental return estimated from fixed firm effects. Results show that the common return and the supplemental return both increased over the years 2001 through 2016 as these farms expanded, and the ratio of worker to operator increased. Moreover, risk analysis indicates that a higher degree of labor leverage increases the standard deviation of return to operator labor. Therefore, we conclude that operators leveraged their own labor by hiring workers and through that process received a higher but more variable return to their fixed labor quantity.

BIOGRAPHICAL SKETCH

Wei Li is a master student at the School of Applied Economics and Management at Cornell University. Before joining Cornell, he attended Zhejiang University in Hangzhou, China, where he received his bachelor's degree in applied psychology in 2018. In the spring of 2017, he was an exchange student at the University of Notre Dame to study economics and mathematics. His academic interests include industrial organization and applied microeconomics. Besides the academic work, he is a huge fan of basketball.

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LIST OF ABBREVIATIONS

COM	Common Return to Operator Labor
DFBS	Dairy Farm Business Summary
LMO	The DFBS Residual Return to Operators
MP	Marginal Product
ROL	Total Return to Operator Labor
SPM	Supplemental Return to Managerial Quality

CHAPTER 1

INTRODUCTION

1.1 Background

Firms usually hire additional employees when they expand their business, which results in a higher ratio of workers to managers. In the field of finance, the concept of ”financial leverage” defines an investment behavior of investors who borrow money to generate greater return to their own money (i.e. equity). Thus, the investors’ equity is leveraged with debt. The same concept can apply to leveraging human capital; that is, firm operators may leverage their own labor by hiring workers’ labor, paying them wages, in order to expand the business and receive a higher return to their own operator labor. In contrast to the large number of studies on financial leverage, little is known about labor leverage. Sherer (1995) examines labor leverage in law firms where the labor leverage is defined as the ratio of associates to partners. The author documents that the degree of labor leverage is related to business strategy, human resource management, and organizational structure. Partners sell legal services and manage law firms, and associates perform the legal services in exchange for their contracted wages. Having all expenses subtracted from revenue, all residual revenue goes to partners, which can be greater or lower than the wage rate paid hired labor. However, Sherer (1995) does not explore this relationship between return on partner’s work and the degree of labor leverage, although it is important to know the relationship between the worker-operator ratio and operator’s return so that the mechanism of change in operator’s return can be determined empirically. The increase in operator's return could possibly be attributed to the additional revenue of expanding the business and the substitution effect between hired labor and owner labor. However, reason for the surge in owners' return may be the degree of labor leverage.

In this article, we use a panel data set of dairy farms in New York State to empirically shed light on the relationship between the degree of labor leverage and the return to operator's labor. In public companies, the salaries of operators (e.g. managers) can be explicitly found in financial statements, and most of their work entails management, while the wage incomes of operators in small firms are usually unobservable, and these operators sometimes do physical labor together with workers. Therefore, the operator's working time consists of both physical labor and management, which makes it difficult to measure the return to the type of work hired workers typically perform, because hired workers may also engage in management activities of various degrees. In order to examine whether operators leverage their labor with hiring workers to increase their return, the measurement of their return is necessary, especially the return to management which is unobservable and difficult to measure.

The dairy industry has some advantages for labor leverage research. First, dairy farms are family farms that are directly managed and operated by the farm owners, so the behavior of farms will not be distorted by the inconsistency of goals between of owners and business managers (i.e. no agency cost). Second, milk is the major product of these dairy farms. Although the farms received revenue by selling other products such as cull dairy cows, excess feed, and male calves in addition to milk, these products are by-products of milk production. Therefore, these dairy farms can be considered as single-output firms, with technology and skills required of workers being relatively homogenous compared to multi-output firms or firms producing different single products. Third, the average herd size of dairy farms has been increasing over the past decades from 61 cows per farm in 1992 to 144 cows per farm in 2012 (MacDonald and Newton, 2014), although the number of dairy farms decreased (Rahelizatovo and Gillespie, 1999; Dong et al., 2016). Concurrent with the increase in farm size, more hired labor was used for milk production, while the operator labor provided by farm operators was relatively constant, which enables us to analyze the role of labor leverage in operator's income.

Because many dairy farms do not establish a salary for the operators, and if they do that salary is adjusted by year end profit and loss, the return to operator's labor is implicit. To measure the return to operator's labor, we propose a production function approach to calculate the unobservable price of operator labor (i.e. return to operator labor). Given a production function, under either profit maximization or cost minimization assumption, the ratio of the marginal products of two inputs are equal to the ratio of their prices. Hence, if the price of one input is observable, such as the wage of hired labor, together with the marginal products of the two inputs derived from the production function, then the unobservable price of the other input can be estimated. Although providing identical amounts of operator labor to the business, some dairy farms generate greater or lower output than the mean output over all data farms. A common production function with estimated fixed effects produces a uniform production function for all dairy farms, while the fixed effect term contains the farm specific management quality that estimates the additional positive or negative return to management. Therefore, the total return to operators can be calculated as the sum of the common return to operator labor derived from the marginal product of the average production function, and the fixed effect supplemental return on management quality.

There are two main contributions of this study. First, we find that operator's return increases with a greater degree of labor leverage measured by the ratio of months of hired labor divided by the months of operator's labor over our sample period from 2001 through 2016, as most of our data farms expanded their business. In addition to revealing the mechanism of labor leverage to enhance total return to operator's labor, our second contribution is introducing an estimation method using fixed effects to measure the unobservable return to operator's labor. Specifically, we employ a production function approach to estimate a common return to operator labor and a fixed effect method to derive supplemental return to management quality. The production function approach holds under either profit maximization or cost minimization assumption, which improves its generalizability, and the fixed effect method is a commonly used method to estimate additional return to management quality (Mundlak, 1961; Alvarez et al., 2004). Other methods have been used to measure management. Bloom and Van Reenen (2007) collect survey data of management practice from over 700 companies in the US and Europe. This survey was expanded in the following years to include companies in Asia, South America, and Africa (Bloom et al., 2016), and has been widely used by other researchers. For instance, Sickles et al. (2019) determine the optimal use of management from the dataset of Bloom and Van Reenen (2007). Bloom et al. (2019) further collect survey data of management practice covering over 35,000 companies in 2010 and 2015 together with the US Census Bureau. Similarly, Bandiera et al. (2017) conduct a survey to investigate the behaviors of CEOs in six large economies. Some studies use productivity to proxy management. For example, Nickell (1996) explores the relationship between competition and firm productivity and argues that management quality can be proxied by productivity. Our study explicitly uses fixed effect terms in a production function to calculate the supplemental return to management.

1.2 Organization of Thesis

This paper is organized as follows. Section 2 review prior research about operator's income, financial leverage, and labor leverage. Section 3 introduces the fundamental production function approach and the empirical strategies that we use to estimate operator's return. We estimate a common return to operator labor and management from a uniform production function for all dairy farms and derive supplemental return to management quality by using the fixed effects for each farm. Section 4 describes the data used in this study. Section 5 shows the empirical results including production function estimates, return to operator labor, and Morishima Elasticity of Substitution, and then discusses the role of worker-operator ratio in explaining the change in operator's return. Section 6 investigates the risk associated with labor leverage. The last section, Section 7, concludes the paper.

CHAPTER 2

LITERATURE REVIEW

2.1 Operator's Income

This paper contributes to the literature on explaining the trend in operator's income by applying the concept of leverage to the labor input in firm production. Prior research mainly focuses on the pay of executives in large companies which has been increasing over the past decades (Gabaix and Landier, 2008; Core and Guay, 2010), especially during the 1980s and 1990s (Frydman and Saks, 2010). Several theories have been proposed to explain the increasing trend in CEO pay.

The first is rent extraction theory which claims that executives have powerful influence on the board of directors who decide the payment to CEO to extract rents (Bebchuk et al., 2002). However, this theory is doubted by Murphy and Zabojnik (2004) who states that board of directors became more independent concurrent with the increasing payment to executives in recent past years. Thus, the rent extraction theory fails to explain the surge in CEO pay. Chalmers et al. (2006) use data from Australia companies to find that the rent extraction is not economically significant. In contrast to the rent extraction theory, Murphy and Zabojnik (2004) argue that the change in the skillset of managers is responsible for the increasing payment. General managerial skills that are useful in any firm, compared to firm-specific knowledge and managerial skills, have been more important since the 1970s. Therefore, the competition in the managerial talent market intensifies, leading to a higher equilibrium wage rate.

Another explanation attributes the surge in CEO pay to increasing firm size. Gabaix and Landier (2008) develop an equilibrium model and provide empirical evidence to argue that the escalation in CEO pay is associated with the size of the firm and the aggregate firm size. Their conclusion is supported by other empirical studies, such as Lin et al. (2013) who analyzed companies with poor performance but high executive compensation and find that firm size is significantly positively related to CEO's compensation. The increase in the compensation of executives is also found to be related to the development in communication technologies that reduce the communication cost (Garicano and Rossi-Hansberg, 2006).

In addition to the extensive research on the compensation of executives, a few studies explored the return to operators in small firms such as family farms, which directly relates to our study. Dressler and Tauer (2015) use a dataset of dairy farms and provide an estimate of the non-pecuniary return, which is psychic benefit from being associated with family business, to family business operators. They arrive at an estimate of $22,026 per year for this non-pecuniary return over 1999 through 2008. Jetté-Nantel et al. (2011) conclude that farm production decisions are correlated with the portfolio of farm operator's income consisting of farm income and off-farm income, regardless of farm sizes. Mishra and Sandretto (2002) find that off-farm income reduce the variability in total farm household income.

2.2 Financial Leverage

The most well-known leverage concept is financial leverage which has been investigated by numerous researchers in past decades. Modigliani and Miller (1958) propose the groundbreaking theory that the value of a firm is not related to the degree of financial leverage in an efficient market and without taxes, bankruptcy costs, agency costs, and asymmetric information. Following their seminal work, researchers advanced the model and proposed theories to determine the optimal degree of financial leverage which maximizes the firm value by examining or relaxing the assumptions in Modigliani and Miller (1958)'s theory. Since firms are always supposed to pay taxes and bear the risk of bankruptcy, trade-off theory was proposed claiming that debt reduces the tax to be paid but increases the bankruptcy risk and thus the value of a levered firm is higher than an unlevered one (Kraus and Litzenberger, 1973). Meckling and Jensen (1976) introduce agency cost into the model and discuss how agency cost can be alleviated by financing with debt. Ross (1977) concludes that firm value is increasing in the degree of financial leverage by assuming the existence of asymmetric information between firms and investors. Firms have the knowledge of knowing firm performance but investors do not. Hence, the degree of financial leverage serves as a signal to investors regarding firm performance and a higher degree of financial leverage implies better firm performance.

Moreover, there also exist extensive empirical studies that shed light on the relationship between financial leverage and firm performance and behaviors. Aivazian et al. (2005) show that financial leverage has a negative impact on a firm's investment decisions especially for the firms with low growth opportunities. Kini et al. (2017) document that firms with higher financial leverage are more likely to recall products at a higher frequency. Matsa (2011) use US consumer price index microdata to show that highly leveraged supermarkets offer lower product quality in terms of product availability. In addition to firm performance and behaviors, financial leverage has been found to be associated with labor markets. Simintzi et al. (2015) provide evidence that labor regulations that increase employment protection reduce firm's financial leverage level using firm-level data from 21 countries covering the period of 1985 through 2007. This conclusion is consistent with Serfling (2016) who documents that the degree of financial leverage decreased after labor protection law was adopted and the dismissal cost for firms increased. But Lin et al. (2018) find that higher direct employee power increases financial leverage by comparing the large firms that are required by law to have an equal number of employee representatives and owner representatives in the board and other firms in Germany, and by exploiting the introduction of this law in 1976 for identification.

2.3 Labor Leverage

Although financial leverage has attracted much attention, labor and capital are both important inputs in firm production, but little attention has been paid to the concept of labor leverage. The definition of labor leverage is inconclusive in the existing research. Sherer (1995) defines the degree of labor leverage, in a law firm context, to be the ratio of the number of associates to the number of partners, and finds that this labor leverage is associated with business strategy, organizational structure, and human resource management. Consistent with Danthine and Donaldson (2002), Donangelo et al. (2019) takes labor leverage as a form of operating leverage due to the inflexibility of labor expenses and proxies labor leverage by the share of labor expenses to total expenses. They document that high labor share firms have higher expected returns, which agrees with the conclusions of Marfe (2015).

These prior studies have explored the role of labor leverage in firm behavior and firm performance but the relationship between labor leverage and return to operators, although important, remains unclear. The companies in Donangelo et al. (2019) are publicly traded companies while, given the important role and the number of small- and medium-sized firms in our economy, it is also crucial to understand how the income of operators in small and medium firms have changed. The current research provides a different angle to the firm size explanation by applying the concept of leverage to the link between firm size and operator's income in a context of family dairy farms where the organizational structure is less complex than that in large publicly traded companies, which enables us to define labor leverage in a more intuitive way. Therefore, applying the concept of financial leverage to the labor input in firm production, the change in operator's income may be explained by labor leverage applying the concept of leverage; that is, operators use labor leverage to generate higher expected return to their own labor at the cost of higher variation in their income.

CHAPTER 3

METHODOLOGY

In this section we show how operator's return is measured. Operator's labor and management is an important input in dairy production. On smaller farms operators work together with hired workers to feed and milk cows, while in larger farms often with thousands of cows, operators often do little physical labor and are more focused on managing the farms. The quality of physical labor is assumed similar across farms since cows need to be fed, carried for, and milked regardless of farm size. However, the management quality may be less homogeneous and vary across farms. Thus output can be different, even if the input quantities are identical, due to varied management qualities. Hence, the total return to operator labor and management consists of a generic return to their labor and management (i.e. common return) and a farm-specific return because of management quality (i.e. supplemental return). A production function approach is proposed to measure the common return to operators with a fixed effect method to measure the supplemental return. The total return then is defined as the sum of the common return and the supplemental return.

3.1 The Production Function Approach

In order to measure the common return to operator labor, marginal products are necessary and thus a production function is required. Suppose the production function for a given farm is

$$Y = F(\boldsymbol{X}),\ Y \in \mathbb{R},\ \boldsymbol{X} \in \mathbb{R}^L_+ \tag{3.1}$$

where Y is the output and $\boldsymbol{X}$ is the inputs of the farm. Although Tauer (1995) concluded that some dairy farms in New York State appear to maximize profits, more farms were minimizing costs, yet every dairy farm is subject to the same technology as specified by the production function. Given any two inputs, the ratio of marginal products should equal the ratio of their prices under either profit or cost optimization condition. Mathematically, the following equation must hold

$$\frac{MP_i}{MP_j} = \frac{\partial F(\boldsymbol{X})/\partial X_i}{\partial F(\boldsymbol{X})/\partial X_j} = \frac{P_i}{P_j}, \forall i, j = 1, 2, ...L \tag{3.2}$$

where MP_i is the marginal product of input i, defined as the derivative of output with respect to the quantity of ith input, and P_i is the price of input i. If P_i is unobservable, such as the return to operator labor in this study, then this equation allows recovering the unobservable price by

$$P_i^U = \frac{MP_i}{MP_j} P_j, \forall i, j = 1, 2, ...L \tag{3.3}$$

where P_i^U is the unobservable price. Thus, the common return to operator labor can be computed by taking advantage of the marginal products and the price of another input. In this study, as in Sickles et al. (2019), we take hired labor and the price of hired labor (i.e. wage) to compute the unobservable common return to operator labor. The price of capital is less explicit than the price of hired labor, which is easily defined and calculated. Although various types of qualities of labor are utilized in farming, that heterogeneity is lower than that of the material input consisting of various categories of goods and services. The common return to operator labor (COM) is calculated as

$$COM = \frac{MP_O}{MP_H} \times wage = \frac{\partial Y/\partial O}{\partial Y/\partial H} \times wage \tag{3.4}$$

where O and H are operator labor and hired labor and MP_O and MP_H are the corresponding marginal products of operator labor and hired labor.

If the technology $F(\cdot)$ is increasing and concave in inputs, and operator labor and hired labor are complementary, then the derived common return to operator is increasing in the worker-operator ratio, that is, the degree of labor leverage. The proof can be found in Appendix B. Ideally, if the production function of each farm is known, then the price of operator labor given by Equation 3.3 is exactly the total return to operator. However, in practice it is hard to know the farm-specific production function. Hence, we assume that the technology of the farms is the same, but the farms are heterogeneous in management quality, and fixed effects are used to calculate the supplemental return to this management quality.

3.2 Fixed Effect Method

The managerial quality is determined by some time-invariant and unique characteristics of operators such as their education level (Fane, 1975) and their personalities (Conway, 2000). Thus, it is reasonable to assume the supplemental return to management quality in each farm to be time-invariant and unique across farms.

Obviously, the management quality is not an input that can be directly used to produce milk; rather, it influences farm productivity. Therefore, it should be captured in the unobservable and time-invariant terms in a fixed effect model. Then the supplemental return is the additional output associated with different management quality in a unit of operator working time. Consider a production function:

$$lnY_{it} = \beta_1 lnX_{1it} + \beta_2 lnX_{2it} + ... + \beta_L lnX_{Lit} + u_i + \varepsilon_{it} \tag{3.5}$$

where i is the farm index and t is the year. Taking the antilog of both sides, we obtain

$$Y_{it} = e^{u_i} X_{1it}^{\beta_1} X_{2it}^{\beta_2} \cdots X_{Lit}^{\beta_L} e^{\varepsilon_{it}} \tag{3.6}$$

The management quality is reflected in the productivity, so e^{u_i} captures the effect of management quality on the output. Then the additional output relative to the average level is

$$\Delta Y_{it} = (e^{u_i} - e^{\bar{u}}) X_{1it}^{\beta_1} X_{2it}^{\beta_2} \cdots X_{Lit}^{\beta_L} e^{\varepsilon_{it}} \tag{3.7}$$

where $\bar{u}$ is the average value of the fixed effects across farms. Thus, the supplemental return to the operators of a specific farm can be calculated by dividing the additional output by the full-time months worked by operators.

Empirically, the fixed effect model allows us to recover the individual farm's fixed effect that can be transformed into the productivity multiplier. In the model described in Equation (3.5), following Greene (2003), the sample expression of the fixed effect is given by

$$\hat{u}_i = \overline{lnY}_i - \hat{\beta}_1 \overline{lnX}_{1i} - \hat{\beta}_2 \overline{lnX}_{2i} - ... - \hat{\beta}_L \overline{lnX}_{Li} \tag{3.8}$$

where $\overline{lnY}_i = \frac{1}{T} \sum_{t=1}^{T} lnY_{it}$ and $\overline{lnX}_{ki} = \frac{1}{T} \sum_{t=1}^{T} lnX_{kit}$. Having estimated u_i, the supplemental return (SPM) is the total additional output ΔY_i divided by the full-time months worked by operators:

$$SPM = \frac{1}{Months} (e^{\hat{u}_i} - e^{\bar{u}}) X_{1it}^{\beta_1} X_{2it}^{\beta_2} \cdots X_{Lit}^{\beta_L} \tag{3.9}$$

Together with the common return (COM) given by the production function approach, the total return to operator labor (ROL) is the sum of the estimated common return and the supplemental return:

$$ROL = COM + SPM \tag{3.10}$$

CHAPTER 4

DATA

The data used in this study is from the Dairy Farm Business Summary (DFBS) (Karszes et al., 2018). This is a dairy farm business analysis project to help farmers better management their business, and to provide data for research on dairy farm management. Data on 585 individual farms are available from the years 2001 through 2016. Data include farm-level expenses, receipts and inventories. As the participation is on a voluntary basis, not all farms participated in the survey for the whole period, hence the data set is an unbalanced panel.

Accrual measures of the expenses and receipts were used, allowing us to compute the value of variables that was actually used or produced each year. Four inputs and one output are specified and utilized in the subsequent empirical analysis. The output is the yearly revenue of each farm. Milk sales comprises over 85% of the total revenue on the farms and the other receipts, such as dairy cattle receipts and crops receipts, are the by-products of producing milk. Thus, it is reasonable to aggregate all of these receipts into the sole output of revenue. The four aggregated inputs are capital, hired labor, operator labor, and material. Before aggregation the receipts and the expenses are deflated into 2016 US dollars by appropriate price indices collected from National Agricultural Statistics Service of United States Department of Agriculture. Table A.1 in Appendix A shows the items included in the output and each input as well as the corresponding price indices used to deflate. The descriptive statistics of the variables can be found in Table 4.1. The farms that only participated in the survey for single year are dropped because a fixed effect term is included in the production function, which requires multiple-year observations to estimate the coefficients.

The capital input is defined as the sum of holding cost and depreciation of farm assets, and other asset-related expenses including fees on machine, building repair, cash rent and real estate tax, where farm assets consist of real estate, machinery, and livestock. To compute the holding cost, the interest rate is calculated by taking the ratio of interest on equity divided by farm net-worth as used in DFBS and is farm-specific. This proxy for holding cost is used because a cost of capital estimate is not possible given these dairy farms are not publicly traded firms, implying that any variation of the CAPM can not be used to arrive at the equity cost of capital. Interest expense is available but farmers varied in financial leverage with some using little or no debt, so that cannot be used as a proxy. The depreciation of real estate and machinery, and the asset-related expenses are included in the data set. Depreciation of livestock is not included in the capital input because most livestock are raised rather than purchased. The costs of raising replacement animals are included in the material and other inputs. Any purchased animals are included in the material input.

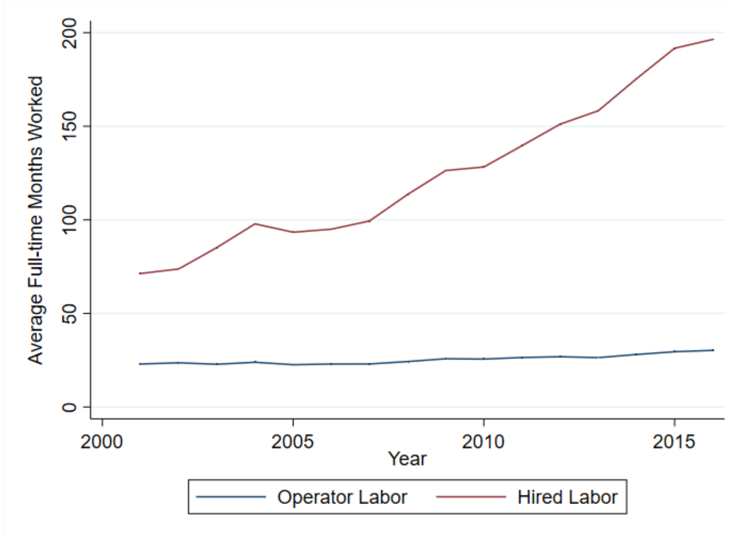


Figure 4.1: Full-time Months Worked by Operators and Workers per Farm by Year

The hired labor input and operator labor input are both reported in the data set in terms of months. Figure 4.1 illustrates the annual average full-time months worked by operators and hired workers. The hired labor is the sum of full-time working months of paid employees and paid or unpaid family labor (not designated as operators). Estimating the production function requires the log value of inputs. Hence, the observations of a few farms that hired no labor were dropped, which is acceptable because the implicit price of operator labor cannot be measured without any hired labor. Some workers in dairy farms were part-time workers. Therefore, the labor leverage in our study is defined as the ratio of the full-time months equivalent worked by hired labor to the full-time months worked by operators. Monthly hired labor wage is calculated by taking the ratio of labor expenses to the full-time working months of hired workers and paid family labor. This wage rate is different across farms and across years. Difference in wages can be due to local employment opportunities across a state that has both rural and urban regions.

Operator labor, consisting of physical labor and management, is defined in a similar way in which the full-time working months of operators in each farm are summed up to obtain the total months worked by all operators. The number of operators differed across farms and the average number is 2.06 in our sample. The material expenses is the sum of the expenses on feed, energy, crops, and livestock-related categories. The DFBS items included in these categories can be found in Table A.1.

Table 4.1: The Descriptive Statistics for Output and Inputs (Year 2016 Dollars)

Variable	Obs.	Mean	Std. Dev	Min	Median	Max
Revenue	2,643	2,751,942	2,813,378	55,175	1,823,473	22,400,000
Capital	2,643	814,908	758,923	35,348	585,918	6,143,000
Hired Labor (months)	2,643	126	126	0.5	88.5	923
Operator Labor (months)	2,643	25.37	13.16	1	24	83.2
Material	2,643	1,835,542	1,844,828	83,770	1,277,192	14,400,000
Wage	2,643	3,384	1,197	196.1	3,317	23,634

CHAPTER 5

EMPIRICAL RESULTS

5.1 Estimated Return to Operator Labor and Management

A White test for the estimated Translog model indicates the existence of heteroskedasticity[$\chi^2(100) = 291.44, p < .001$], hence the Cobb-Douglas and the Translog production functions were estimated by feasible generalized least square (FGLS) in order to address heteroskedasticity. In addition, the endogeneity problem is alleviated by using the fixed effect model, which acts as control variable for management skill. When estimating the fixed effect model, time-invariant variables included in the unobserved term are eliminated and so is the bias caused by omitted variables.

Regression results are shown in Table 5.1. In the Cobb-Douglas model, the signs of the coefficients are all consistent with expectations and statistically significant. Moreover, the sum of the estimated coefficients is 1.0534, statistically greater than one, suggesting an increasing return to scale technology. This is consistent with the observed increase in farm size over the period to capture economies of size. The significance of the time variables, which exhibited an increasing but concave relationship, implies that technological progress occurred over the period but at a decreasing rate. These results are similar for the Translog estimates also reported in Table 5.1. The only difference is that the coefficient of hired labor in the Translog model is negative. However, the interaction term between hired labor and material is significantly positive. Thus, taking the interaction effect into account, the joint effect of hired labor on the revenue is positive on average.

Estimates are comparable to previous production function estimates of dairy farms. Byma and Tauer (2010) use the DFBS dataset over the period of 1993 and 2004 and estimate an output distance function in the translog functional form. Although the non-significant coefficient of operator labor in our model is in line with Byma and Tauer (2010), the coefficient of hired labor is significantly negative. Moreover, the estimated coefficient of capital input in their model is 0.0492 in comparison to 0.5076 in the current research. This discrepancy can be explained by the technological development and the structural change in the dairy farms participating in the survey across the two periods.

A Wald test indicates that all coefficients of the squared and interaction terms in the Translog model are significantly jointly positive [$\chi^2(10) = 185.41, p < .001$], suggesting that these terms cannot be excluded and the Translog model fits the production data better than the Cobb-Douglas functional form. Thus, the subsequent calculations and analyses are based on the results of the Translog model. Specifically, we derive the marginal products and recover the farm-specific fixed effects using the Translog model, which are then used to calculate the common return and supplemental return on operator labor and management.

Table 5.1: Estimates of New York Dairy Farm Production Functions

	Cobb-Douglas ln Revenue	Translog ln Revenue
ln Capital	0.2899***	0.5076**
	(67.66)	(2.32)
ln Hired Labor	0.0627***	-0.4069**
	(19.20)	(-3.38)
ln Operator Labor	0.0302***	0.1376
	(10.98)	(1.50)
ln Material	0.6706***	1.5618***
	(150.41)	(8.98)
T	0.0330***	0.0316***
	(52.15)	(32.35)
T^2	-0.0010***	-0.0009***
	(-18.38)	(-12.78)
(ln Capital)^2		0.0679***
		(5.11)
(ln Hired Labor)^2		0.0058
		(1.30)
(ln Operator Labor)^2		0.0038
		(3.47)
(ln Material)^2		0.0338**
		(2.19)
ln Capital × ln Hired Labor		0.0011
		(-0.07)
ln Capital × ln Operator Labor		0.0135
		(0.98)
ln Capital × ln Material		-0.1487***
		(-6.37)
ln Hired Labor × ln Operator Labor		-0.0089
		(-0.83)
ln Hired Labor × ln Material		0.0346*
		(2.22)
ln Operator Labor × ln Material		-0.0187
		(-1.58)
Constant	0.6109***	-5.9439***
	(11.64)	(-5.28)
N	2643	2643
χ^2	436137	392730
p	.000	.000

t statistics in parentheses

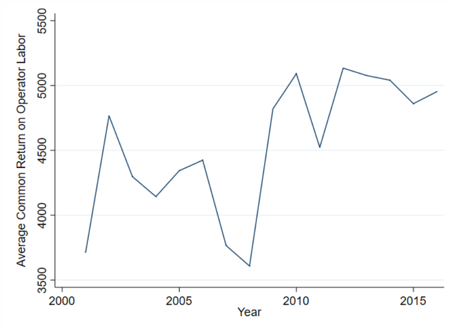
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5.2: Monthly Return to Dairy Farm Operator Labor and Management (2016 Dollars)

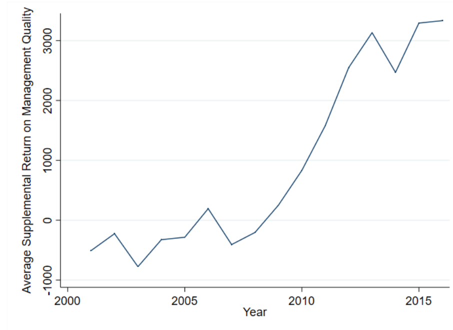
Variable	Obs.	Mean	Std. Dev	Min	Median	Max
Supplemental Return	2,643	865	11,872	-119,709	-67	106,125
Common Return	2,643	4,513	6,558	-204,375	4,121	88,235
Total Return	2,643	5,378	14,130	-202,995	3,800	123,564

Using the estimated return to operator labor and management as summarized in 5.2, the operators of the dairy farms in our sample earned $5,378 dollars per month (in terms of 2016 US dollars) on average. In particular, the common return is $4,513 dollars per month and the supplemental return to management quality is $865 dollars per month. The monthly total return of $5,378 dollars implies an annual income of $64,536 dollars. The mean value of supplemental return is 865 dollars while its median is -67 dollars. Hence, the difference between the mean and the median of supplemental return suggests that the distribution of supplemental return skews to the right.

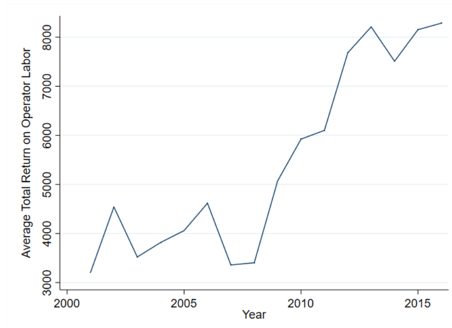
Common return is associated with the marginal product of operator labor and hired labor. Therefore it is also associated with the input quantities, which implies that the fluctuation in common return can be due to the change in the input quantities. Supplemental return is calculated by dividing the additional output by the months worked by operators, while the additional output is correlated with the receipt in a given year. Given fixed managerial quality, a higher revenue will result in a higher supplemental return. Therefore, the fluctuation in supplemental return during the sample period can be attributed to different annual revenue, although it is possible that operators may work more in a good year when the revenue is high and the opposites holds in a bad year, which decreases or increases supplemental return.



(a) Monthly Common Return



(b) Monthly Supplemental Return



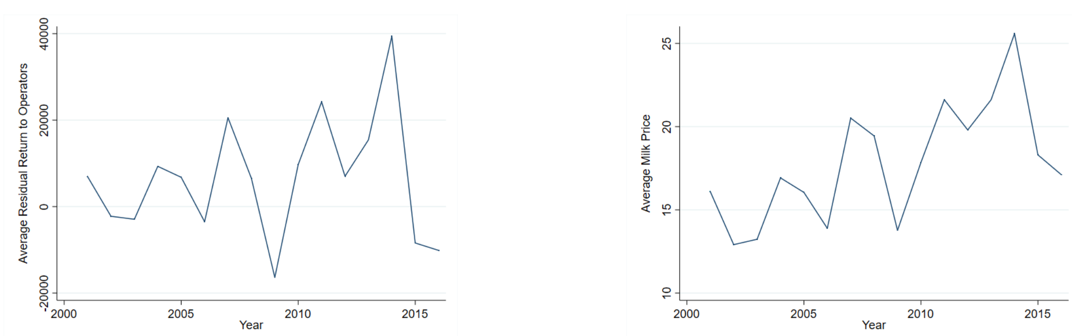
(c) Monthly Total Return

Figure 5.1: Monthly Returns to Dairy Farm Operator Labor and Management

5.2 Correlation Between the Estimated Return and DFBS Residual Return

Because the owners of these dairy farms are also the operators, the profit, either positive or negative, accrues to the operators. Therefore, intuitively profit can serve as another measurement of operator income in dairy farms. The DFBS dataset defines and provides an estimate of the yearly income of operators as the residual of net farm income (without appreciation) after subtracting unpaid family labor and an opportunity cost of equity capital. Return to operators in the DFBS dataset is computed by dividing this yearly residual income by the number of full-time months worked by operators. The DFBS report uses a fixed real interest rate of 5% to calculate the opportunity cost of equity capital, which is assumed to be the long-term average real return rate of a risky investment, and is very close to the farm-specific interest rate used in our estimation of 5% on average. Figure

5.2 shows the time trend change in the residual return calculated by dividing the residual income by the full-time months worked by operators and then deflated by CPI indices. The average milk price each year is also included in Figure 5.2. The residual return is greatly influenced by the fluctuation in the milk price to a large extent. For example, the average milk price in 2014 was \$25.59/cwt, much higher than the overall average milk price across the sample period of \$17.61/cwt. Hence, the residual return to operators in 2014 was extremely high at \$39,402 per month, which greatly exceeded the overall average return of \$6,448 per month. In comparison, the decline in the price of milk in some years, which decreased greatly from \$19.44/cwt in 2008 to \$13.77/cwt in 2009, for instance, resulted in a low operator return in the DFBS computed monthly return to operators in 2009. Along with the milk price, the residual return to operators also shrank from \$6,531 per month in 2008 to \$-16,386 per month in 2009.



(a) Monthly Residual Return to Operators (b) Average Milk Price in Each Year (\$/cwt)

Figure 5.2: Monthly Residual Return and Milk Price

By calculating the correlation between the two measurement of return to operators, our estimate from the estimated production function and the estimate reported in the DFBS report, we find that our derived return to operators are positively correlated with the DFBS return ($r = 0.3646,\ p < .001$). An explanation of the difference is that the common return component in our derived return is a marginal return to generic operator labor, where the return estimated from the DFBS is an average concept. Our analysis also assumes that farms are assumed to be producing milk under profit maximization or cost minimization behavior. This assumption may not hold in practice, which may also explain the discrepancy of $1580 per month between the average derived return from our estimates and the average residual return from the DFBS.

5.3 The Morishima Elasticity of Substitution

In addition to estimating the return to operator labor, the elasticity of substitution for the inputs pairs of the four inputs used by the farms in producing milk were calculated. Blackorby and Russell (1981) show that the Morishima Elasticity of Substitution can be written as

$$M_{kj} = \frac{\partial lnP_j}{\partial lnX_k} - \frac{\partial lnP_k}{\partial lnX_k}, \ \forall k, j = 1, 2, ..., L \tag{5.1}$$

where P_j is the price of the jth input, X_k is the kth input,and L is the number of inputs in a production function. Since the price of hired labor (i.e. wage) is assumed to be exogenous in this study, the derivatives of wage with respect to all inputs are zero. The price of operator labor is given by the sum of the common return to operator generic labor and the supplemental return to management as discussed in the previous sections. However, the prices of capital and material remain unclear because these two inputs consist of expenses from many different categories. Therefore, the price of the two inputs are derived in the same way as the common return to operator generic labor as:

$$\begin{aligned} P_{capital} &= \frac{MP_k}{MP_h} \times Wage, \\ P_{material} &= \frac{MP_m}{MP_h} \times Wage \end{aligned} \tag{5.2}$$

where MP_k is the marginal product of capital, MP_m is the marginal product of material, and MP_h is the marginal product of hired labor.

Due to the asymmetry of the Morishima Elasticity of Substitution (Blackorby and Russell, 1981), we compute the elasticity of substitution for the twelve combinations of capital, hired labor, operator labor, and material. According to Equation 5.1, the Morishima Elasticity of Substitution is equal to the sum of cross-quantity elasticity and own-quantity elasticity. Therefore, a positive elasticity of substitution implies that the two inputs are complementary. Since own-quantity elasticity is always non-negative (with the minus sign), the positive cross-quantity elasticity for two complementary inputs results in a positive elasticity of substitution. Obviously, two inputs are substitutes if the elasticity of substitution is negative. The magnitude of the Morishima Elasticity of Substitution also matters. A small positive value of elasticity of substitution suggests it is easy to substitute one input for the other while a larger positive value suggests exactly the opposite (Sickles et al., 2019).

Table 5.3: The Morishima Elasticity of Substitution for Four Inputs

Input Pairs	N	Mean	Std. Dev	Min	Median	Max
Capital for Hired Labor	2,643	0.500	0.150	-2.391	0.510	2.652
Hired Labor for Capital	2,643	0.868	1.150	-21.31	0.908	32.25
Capital for Operator Labor	2,643	0.786	1.767	-41.13	0.807	44.97
Operator Labor for Capital	2,643	-0.231	5.742	-223.3	-0.021	37.28
Capital for Material	2,643	0.252	0.097	-0.397	0.261	0.472
Material for Capital	2,643	0.331	0.107	-0.399	0.344	0.577
Hired Labor for Operator Labor	2,643	-0.591	11.70	-403.3	-0.216	66.03
Operator Labor for Hired Labor	2,643	-0.387	5.815	-223.6	-0.193	37.07
Hired Labor for Material	2,643	0.919	1.150	-21.27	0.958	32.29
Material for Hired Labor	2,643	1.301	3.449	-92.78	1.182	67.82
Operator Labor for Material	2,643	-0.311	5.742	-223.4	-0.101	37.20
Material for Operator Labor	2,643	-0.764	48.45	-1709	0.875	301.1

The elasticity of substitution of the four inputs are reported in Table 5.3 and their distributions across the farm data are displayed in Figure 5.3 [1]. It can be concluded that capital, hired labor, and material are complementary inputs because the average values of the elasticities of substitution between these inputs are positive, which is consistent with our expectation. However, operator labor and any of the other three inputs are substitutes due to the negative elasticities of substitution.

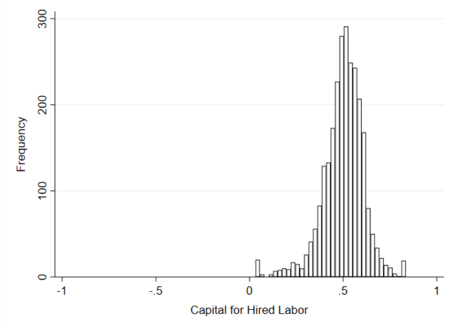
Our main interest is in the elasticities of substitution for hired labor and operator labor. Because

[1] The values smaller than 0.5 percentile or greater than 99.5 percentile are dropped in the figures

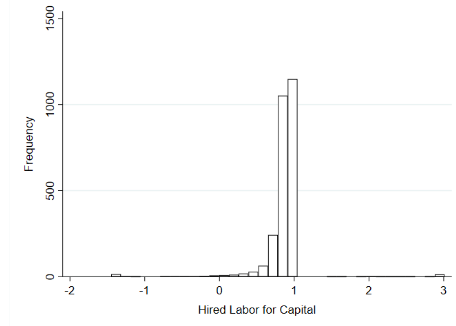
hired labor is selected to be the numeraire input, the cross-quantity elasticity between hired labor and operator labor is zero. Hence, the elasticity of substituting operator labor for hired labor is equal to the additive inverse of the own-quantity elasticity of operator labor, which implies that the own-quantity elasticity of operator labor is positive. The reason for the positive own-quantity elasticity of operator labor can be the endogeneity of operator labor. In constrast to the other inputs whose quantities decrease when their corresponding prices go up, operators will work more and provide more operator labor when the return to operators increases. Therefore, the own-quantity elasticity of operator labor is positive.

The bottom row of Figure 5.3 illustrates the distributions of the elasticities of substitution for hired labor and operator labor. The median values are greater than the mean values for both elasticities, which implies that the distributions of the two elasticities are both skewed to the left. The difference in the average values of two elasticities between operator labor and hired labor suggests that it is less difficult to replace operator labor with hired labor. This might be due to the heterogeneity in operator labor and hired labor. The majority of the tasks performed by hired workers are physical labor such as milking and feeding cows, although operators also can complete these tasks. In fact, the operators of some small farms often work with hired workers and are capable of doing the physical labor. However, management is also part of operator labor. The major responsibility of operators in large farms is managing the farm, which requires a unique skillset which most hired workers have not developed. Hence, it is easier to substitute operator labor for hired labor than substitute hired labor for operator labor. Such discrepancy in the skillset of hired labor and operator labor also explains the ease of substitution between hired labor, operator labor, and capital.

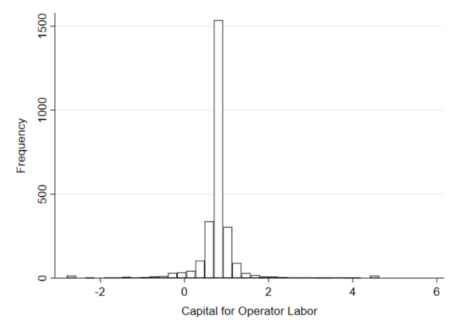
The first row in Figure 5.3 shows the distributions across farms of the elasticities of substitution for capital and hired labor, where it is easier to substitute capital for hired labor than the opposite direction. Moreover, the second row indicates that it is easier to substitute operator labor for capital than to substitute capital for operator labor. These two conclusions can both be explained by the different skillsets of operator labor and hired labor discussed in the previous paragraph. Hired labor is more general while operator labor constitutes a higher and more technical skillset. The physical tasks assigned to hired workers, along with the development in technology, can be completed by machines. Therefore, hired labor can be more easily replaced. In contrast, the management part in operator labor is very difficult to be replaced with capital. Thus, capital may be substituted for hired labor but less easily for operator labor.



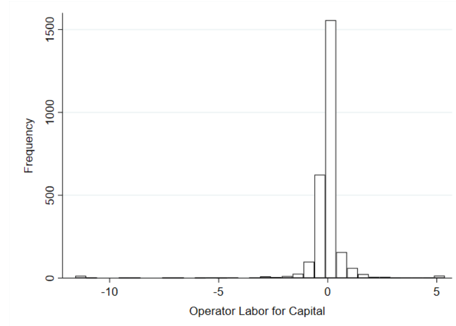
(a) Capital for Hired Labor



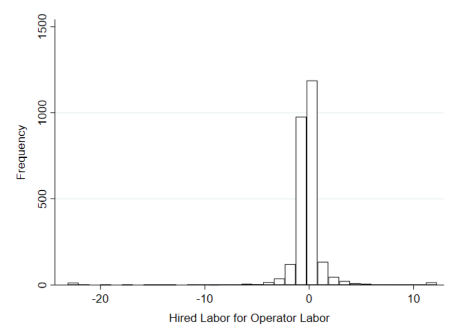
(b) Hired Labor for Capital



(c) Capital for Operator Labor



(d) Operator Labor for Capital



(e) Hired Labor for Operator Labor

(f) Operator Labor for Hired Labor

Figure 5.3: The Morishima Elasticity of Substitution

5.4 Labor Leverage and Return to Operators

Figure 5.1 shows the time trend of return to operator labor and management. It is clear that the common return, although fluctuating over the years, and the supplemental return, both show an increasing trend. The increase in the common return can be attributed to the change in the marginal products of operator labor and hired labor, because the constant dollar wage rate did not change much over this period. The maximum average wage rate across the farms is 3,491 dollars per month and the minimum is 3,202 dollars per month. Thus, the ratio of the marginal products is responsible for the fluctuation in the common return. From 2001 to 2016, the average dairy farm size, in terms of the number of cows, increased, which required more workers to take care of the additional cows resulting in a higher worker-operator ratio. Hence, operators hired more labor to shift their own efforts from physical labor to more management, with a surge in the marginal product of operator labor. The marginal product of hired labor did not increase as much as the marginal produce of operator labor, since the tasks they performed on these dairy farms did not change over the time. Workers performed physical labor tasks, such as feeding and milking cows, the skills of which change little over this time period even with technological change. Therefore, the marginal product of hired labor was relatively constant compared to the marginal product of operator labor as supported by our empirical results. Figure 5.4(a) shows the marginal products of operator labor and hired labor over time. The curve of the marginal product of hired labor increases less than the curve of the marginal product of operator labor. However, the marginal product of hired labor may have increased slightly concurrent with farm size if laborer became more specialized in the tasks they performed rather than being a general farm worker. With the marginal product ratio shown in Figure 5.4(b), it can be concluded that the ratio of the marginal product of operator labor to the marginal product of hired labor increased from 2001 through 2016. Since the common return to operator labor is positively related to the ratio of the two marginal products, the common return to operators increased over the sample period.

(a) Marginal Products

(b) Ratio of Marginal Products

Figure 5.4: Marginal Products of Operator Labor and Hired Labor

The change in the supplemental return fluctuated less wildly and increased with time [2]. Since we are assuming with a fixed effects estimate that the managerial ability and the managerial quality of operators were time-invariant, the increase in the supplemental return may be explained by the degree of labor leverage (i.e. the ratio of workers to operators). In a very small farm, operators would do most or all of the required physical labor such that they spent less time on management tasks, and the additional output associated with the operators' managerial ability was negligible. As the farm expanded and more workers were hired, management became more prevalent than on a small farm. A higher worker-operator ratio implies a more important role of management in farm production because a higher worker-operator ratio suggests more workers were assigned to different tasks by the given operators. Thus, the additional output from management increased. According to Equation 3.9, for a fixed number of full-time months worked by the given operators, the supplemental return increases in additional output. Hence, a higher worker-operator ratio increases the additional output which leads to a higher supplemental return to management.

[2]The dataset is an unbalanced panel so some farms exited and some entered the panel. Thus change in the composition of observed farms may have also contributed to the change in the supplemental return

CHAPTER 6

RISK ANALYSIS

6.1 Risk Associated with Leverages

It is well-known that a higher degree of financial leverage is associated with higher risk and higher expected return. If an investment fails, then the investor not only loses his or her own equity, but also needs to repay the debt. Thus the loss is amplified. On the other hand, an investor will receive a higher return compared to the return without debt, if the investment succeeds. Therefore, higher risk is associated with a higher debt-equity ratio. Since most people are risk averse, a risk premium in the expected return is required to compensate for the risk associated with financial leverage. Due to the similarity between financial leverage and labor leverage, a higher degree of labor leverage should also result in a higher expected return to operators but with a greater variance in the return because of the inflexibility of hired labor expense (Donangelo et al., 2019). Consider two single-operator firms of which one hires more employees than the other. In a good year when both firms are profitable, the operator of the firm with more employees should earn more than his counterpart, as discussed previously that the return to the operator is increasing in the worker-operator ratio. However, his income would be lower than the income of the other operator when both firms are facing losses because more employees implies higher labor expense that amplifies the loss. Therefore, this section aims to show empirically that both the expected return to operators and the variance of return are increasing in the degree of labor leverage, using two types of return to dairy farm operators, our derived return and the residual return calculated in the DFBS.

For both types of the return to operators, we take the average return in the corresponding sample period of each farm as the expected return and take the sample standard deviation of the returns for a given farm over the years as the population standard deviation of the return distribution. The farms participating in the survey for only one year are excluded because the standard deviation of such farms cannot be calculated. Hence, only farms with two years or more are used for calculation. Then we regress the following four statistics on average labor leverage and average financial leverage, which is calculated by taking the ratio of total debt to asset in each farm, using OLS with robust standard errors:

$$\begin{cases} E(ROL) = \dfrac{1}{T}\displaystyle\sum_{j=1}^{T} ROL_j \\ SD(ROL) = \sqrt{\dfrac{1}{T-1}\displaystyle\sum_{j=1}^{T}[ROL_j - E(ROL)]^2} \\ E(LMO) = \dfrac{1}{T}\displaystyle\sum_{j=1}^{T} LMO_j \\ SD(LMO) = \sqrt{\dfrac{1}{T-1}\displaystyle\sum_{j=1}^{T}[LMO_j - E(LMO)]^2} \end{cases} \tag{6.1}$$

where ROL is our estimated return to operator labor and management, LMO is the DFBS calculation of the residual return to operators, and T is the years in which the farm participated in the survey. Farm size, in terms of the number of cows, is not included as a control variable in the regressions because of multicollinearity. By our definition of labor leverage, which is the ratio of the months worked by hired workers to the months worked by operators, large farms tend to have a higher degree of labor leverage while small farms are less likely to maintain a high worker-operator ratio. Therefore, the farm size is highly correlated with the degree of labor leverage, causing the effect of labor leverage hard to be identified, and thus it is not included in the regression.

6.2 Results

The regression results are showed in Table 6.1. It is very clear that the coefficients of labor leverage on the standard deviation of both types of return to operators are significantly positive, implying that a higher degree of labor leverage leads to a more variable return. A higher degree of labor leverage not only generates higher return to operators in good years but also amplifies losses in bad years. Hence, the variance of return to operators in a farm with higher worker-operator ratio is greater. However, the effect of labor leverage on the average return is less consistent across the two types of return. The coefficient of labor leverage using our estimated return is not significantly different from zero but the coefficient on the DFBS residual return is marginally significantly positive. One possible reason is that there are some farms which participated in the survey for only a few years. Thus the mean value of the return in such farms is less informative and can deviate greatly from the true expected return. The risk analysis shows that the return to operators in the farms with a higher worker-operator ratio tends to be more variable, but the relationship between the expected return and the degree of labor leverage remains unclear.

In contrast to the non-significant effect of labor leverage on the mean values of the estimated return and the DFBS residual return, financial leverage has a significantly negative impact on the mean values, which implies that higher degree of financial leverage leads to a lower expected return to farm operators. On the other hand, the coefficients of financial leverage on the standard deviations of the estimated return is significant while the coefficient on the DFBS residual return is not, indicating that financial leverage has a negative impact on the variation in the estimated return but it is not correlated with the variation in the DFBS return.

Table 6.1: Results of Risk Analysis of Leverage

	(1) $E(ROL)$[1]	(2) $SD(ROL)$[2]	(3) $E(LMO)$[3]	(4) $SD(LMO)$[4]
Labor Leverage	283.28	250.76***	820.35*	2704.24***
	(0.65)	(4.22)	(1.94)	(8.43)
Financial Leverage	-14187.85***	-7317.36***	-9379.90**	-2212.27
	(-3.16)	(-2.69)	(-2.32)	(-0.64)
Constant	8188.27***	4067.49***	3993.73**	1125.53
	(4.54)	(3.24)	(2.26)	(1.20)
N	352	352	352	352
R^2	0.05	0.09	0.13	0.70
F	5.16	15.53	3.51	53.70
p	0.0062	0.0000	0.0308	0.0000

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

[1] The average value of the estimated total return to operator labor

[2] The standard deviation of the estimated total return to operator labor

[3] The average value of the DFBS residual return

[4] The standard deviation of the DFBS residual return

CHAPTER 7

CONCLUSION

This thesis introduces a method to estimate the unobservable return to operators in small firms and examines the role of labor leverage in explaining the change in return to operators as hired labor increases relative to operator labor, using a unique panel data set of dairy farms in New York State from 2001 through 2016. In contrast to the operators in publicly traded companies, the incomes of the operators in small firms, such as the family dairy farms in this study, are usually unobservable and thus requires an estimation. We separate total return to operator labor into two parts, a common return to generic operator labor and a supplemental return depending on operator's management quality. Under either profit maximization or cost minimization assumption, the ratio of marginal products of any two inputs is equal to the ratio of their prices. Therefore, we derive the common return to operator labor using an average production function uniform across all farms and the corresponding marginal products based on the input quantities. The supplemental return is calculated using the farm-specific fixed effects estimated from the average production function. These fixed effect term captures the effect of management quality on output. Hence, supplemental return is the quotient of the additional output due to different management qualities to the full-time months worked by operators.

Both the common return and the supplemental return increased over time. During the time period of 2001 through 2016, the dairy industry and the dairy farms experienced a growth in farm size. Farms expanded their herd size and hired more workers. However, the number of operators remained relatively constant, which results in an increasingly higher worker-operator ratio; that is, a higher degree of labor leverage. More workers enable operators to do fewer physical tasks and perform more management. Thus, the marginal product of operator labor increased, leading to a higher common return. Meanwhile, the supplemental return increased because the management was playing a more important role in farm production with more workers hired. Although the managerial ability of operators is assumed to be time-variant, the additional output from managerial quality increased and thus the supplemental return surged. Therefore, a higher degree of labor leverage can be the reason for the increase in return to operators. In other words, operators utilize increased labor quantities from hired workers to leverage their own fixed labor and generate higher return to operator labor relative to the cost of paying worker wages. A subsequent risk analysis shows that the average return to operators is not affected by the degree of labor leverage but the standard deviation is greater in farms with a higher worker-operator ratio. Hence, labor leverage is positively associated with the variance in the return to operators. In conclusion, this study provides a new perspective and approach to explain the change in the income of operators. By applying the concept of financial leverage to human capital, we conclude that firm operators receive a higher but more variable return with a higher degree of labor leverage. Future research can examine the relationship between labor leverage and operator's income in a more complex organizational structure such as in large public companies.

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APPENDIX

A Input Aggregation for New York Dairy Farm Data

Table A.1: Aggregated Variables and Price Indices

Variables	DFBS Items	Price Index
Capital	Real Estate Depreciation	Buidlding Material
	Machinery Depreciation	Machinery
	Real Estate Beginning Market Value	Buidlding Material
	Real Estate Ending Market Value	Buidlding Material
	Beginning Machinery Inventory	Machinery
	Ending Machinery Inventory	Machinery
	Machine Hire, Rent and Lease Expenses	Rent
	Machine Repairs and Farm Vehicle Expenses	Repair
	Land, Building and Fence Repair Expenses	Repair
	Taxes	Tax
	Rent and Lease Expenses	Rent
Hired Labor	Full-Time Number of Month Worked by Hired Labor	
	Full-Time Number of Month Worked by Family (Paid)	
	Full-Time Number of Month Worked by Family (Unpaid)	
Operator Labor	Full-Time Months Worked by Operators	
Material	Dairy Grain and Concentrate Expenses	Concentration
	Dairy Roughage Expenses	Forage
	Nondairy Feed Expenses	Feed
	Fuel, Oil and Grease Expenses	Fuel
	Utilities Expenses	Production Item
	Fertilizer and Lime Expenses	Fertilizer
	Seeds and Plants Expenses	Seeds
	Spray Expenses	Chemical
	Replacement Livestock Expenses	Cull Cow
	Expansion Expenses	Cull Cow
	Cattle Lease Expense	Cull Cow
	Other Livestock Expenses	Supplies
	Breeding Expense	Agricultural Service
	Veterinary & Medicine Expenses	Agricultural Service
	Milk Marketing Expenses	Agricultural Service
	Milking Supplies Expenses	Supplies
	Custom Boarding Expenses	Agricultural Service
	bST Expenses	Agricultural Service
	Insurance Expenses	Agricultural Service
	Miscellaneous Expenses	Agricultural Service
Revenue	Milk Receipts	Milk
	Dairy Cattle Receipts	Cull Cow
	Dairy Calves Receipts	Cull Cow
	Other Livestock Receipts	CPI
	Crop Receipts	Feed
	Government Receipts	CPI
	Custom Machine Work Receipts	Machinery
	Gas Tax Refunds	Tax
	Other Receipts	CPI

B Proof of Common Return Increasing in Labor Leverage

Suppose a production function for a firm is $Y = F(\boldsymbol{X}),\ Y \in \mathbb{R},\ \boldsymbol{X} \in \mathbb{R}^n$. The price p_i of input i is unobservable but the price p_j of input j is exogenous and observable. Then p_i can be calculated by

$$p_i = \frac{MP_i}{MP_j} p_j \tag{7.1}$$

where $MP_i = \frac{\partial Y}{\partial x_i}$ is the marginal product of input i. Because the marginal products are functions of inputs, the estimated p_i is also a function of inputs and can be differentiated with respect to inputs.

Assuming independence between x_i and x_j, the derivative of p_i with respect to input j can be written as

$$\frac{\partial p_i}{\partial x_j} = \frac{\partial p_i}{\partial \frac{x_j}{x_i}} \frac{\partial \frac{x_j}{x_i}}{\partial x_j} = \frac{1}{x_i} \frac{\partial p_i}{\partial \frac{x_j}{x_i}} \tag{7.2}$$

Therefore, by multiplying the first and third terms by x_i, the derivative of p_i with respect to $\frac{x_j}{x_i}$ can be written as

$$\frac{\partial p_i}{\partial \frac{x_j}{x_i}} = \frac{\partial p_i}{\partial x_j} x_i \tag{7.3}$$

Substituting Equation 7.1,

$$\begin{aligned}\frac{\partial p_i}{\partial \frac{x_j}{x_i}} &= \frac{\partial(\frac{MP_i}{MP_j}p_j)}{\partial x_j}x_i \\ &= \frac{\partial \frac{MP_i}{MP_j}}{\partial x_j}p_j x_i \\ &= \frac{\frac{\partial MP_i}{\partial x_j}MP_j - \frac{\partial MP_j}{\partial x_j}MP_i}{MP_j^2}p_j x_i \\ &= \frac{\frac{\partial^2 Y}{\partial x_i \partial x_j}MP_j - \frac{\partial^2 Y}{\partial x_j^2}MP_i}{MP_j^2}p_j x_i \\ &= \frac{F_{ij}F_j - F_{jj}F_i}{(F_j)^2}p_j x_i\end{aligned} \tag{7.4}$$

where F_i is the first order derivative of $F(\cdot)$ with respect to input i, F_{jj} is the second order derivative of $F(\cdot)$ with respect to input j and F_{ij} is the derivative of F_i with respect to x_j.

Suppose $F(\cdot)$ is increasing and concave in $\boldsymbol{X}$, and x_i and x_j are complementary, then $F_i > 0,\ F_j > 0$ and $F_{ij} > 0,\ F_{jj} < 0$. Due to the non-negativity of p_j and x_i, it can be concluded that

$$\frac{\partial p_i}{\partial \frac{x_j}{x_i}} \geq 0 \tag{7.5}$$

when the production function is increasing and concave with x_i and x_j being complementary.

This conclusion holds for any two inputs including operator and hired labor in the dairy farm case. Let x_i be operator labor and x_j be hired labor, then p_j is wage rate. The non-negative derivative suggests that the common return to operator labor is increasing in the worker-operator ratio (i.e. the degree of labor leverage), if the technology is increasing and concave, and operator labor and hired labor are complementary inputs.