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Education, Labor Quality, and U.S. Agricultural Growth[1]

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Abstract

This study employs a Tőrnqvist index approach to construct quality-adjusted labor index for the U.S. farm sector using the volume (hours worked) of 192 demographic components and their corresponding cost shares. We decompose labor input change into quality change and quantity change. The results show that between 1948 and 2011 the decline of total hours worked resulted in -0.58 percentage points of output growth per year while increasing labor quality contributed to 0.08 percentage points of annual output growth. We further decompose labor quality change into a change in the educational attainment of the labor force and a change due to other factors. Our results show that the education component contributed to most of the labor quality changes during the study period. However, the contribution of educational attainment is greater in earlier years than in later years.

Keywords: Tőrnqvist index, educational attainment, labor quality, labor productivity, U.S. agriculture

JEL codes: O13, O15, Q10, Q16

I. Introduction

U.S. real farm production more than doubled between 1948 and 2011, growing at an average annual rate of 1.49% (Ball et al. 2013). Agricultural output growth was mainly driven by a growth in total factor productivity (TFP), at the rate of 1.42% per year, with a slight contribution from an overall agricultural input growth. The estimate of TFP growth is the difference between output growth and input growth. Therefore, TFP measures the output growth that cannot be explained by input growth alone. Jorgenson and Griliches (1967) note that "..changes in total factor productivity have been given such labels as the Residual or the Measure of our Ignorance" and try to explain the sources of productivity changes. Kendrick (1956) and Solow (1957) stated that the changing quality of the labor force may be an important component of the source of the "residual" as most of the observed economic growth was not explained by conventional labor measures. Schultz (1960) linked the role of education to the "residual" by estimating the contribution of total human capital in U.S. output growth. His results showed that human capital accounted for one-fifth of total output growth. Denison (1979) finds that rising educational attainment contributed 0.52 percentage points to national income growth between 1948 and 1973, accounting for 14 percent of that total economic growth.

Regarding labor measurement, Jorgenson, Gollop, and Fraumeni (1987, JGF thereafter) asserted that hours worked are heterogenous. For example, observed wages of an experienced worker with advanced education are usually higher than the hourly wage from a less experienced and less-educated worker. Therefore, they propose that hours should be disaggregated by the characteristics of individual workers categories to generate a constant quality index of labor input that accounts for substitution between different types of labor. Under this context the

estimated labor input is a constant quality index and labor input growth can then be decomposed into quality change and quantity change components.

Since the literature has shown the importance of human capital, particularly education attainment, to economic progress, understanding how education has contributed to farm worker's labor quality and thus agricultural output growth can help to understand the role of education in farm production. The purpose of this study is three-fold: first, to decompose the total labor growth into the change in labor quantity and the change in labor quality; second, to account for the contribution of educational attainment in labor quality change, and in total agricultural output growth; and third, to examine how labor productivity evolved over time in U.S. farm sector based on alternative labor measurement.

II. Methodology

Quality-adjusted labor measurement

To measure a constant quality index of labor input, as originally defined by Jorgenson and Griliches (1967), we employ Tŏrnqvist index approach to measure prices and quantities of hired labor, and self-employed/unpaid family labor using the cross-classified demographical information in the employment, hours worked, and compensation matrices. In our estimates the value of labor input equals the value of labor payments plus the imputed value of self-employed/unpaid family labor. The imputed wage is set equal to the mean wage of hired workers with the same demographic characteristics.

We assume that labor input $\{L\}$ can be expressed as a translog function of its individual components, $\{L_l\}$.

$$ln\frac{L_t}{L_{t-1}} = \sum \frac{1}{2}(v_{lt} + v_{lt-1}) ln\frac{L_{lt}}{L_{lt-1}} \qquad (1)$$

where *ln* is the translog term, $\frac{1}{2}(v_{lt} + v_{lt-1})$ is the average cost shares of each component *l* in the value of sectoral labor compensation in two time periods *t* and *t-1*. L_{lt} is the labor input of the *l*th demographic group.

Since the matrices of employment, hours worked, and compensation per hour (for hired labor) are cross-classified by gender (male or female), age (8 groups), education (6 categories; 5 categories before year 1980), and employment class (hired or self-employed or unpaid workers) there are 192 demographic components (160 components for the data before 1980 due to changes in survey questionnaire regarding educational attainment) in constructing the Tőrnqvist indexes of labor input (table 1). Under the Tőrnqvist index technique, these indexes reflect changes in the demographical composition of hours worked. For example, labor quality rises if components with higher compensation of labor input per hour are growing more rapidly, and falls otherwise. As a result, the price and quantity series for labor input are measured in constant-efficiency units, which are adjusted for compositional shifts (or "quality" change, as termed by JGF). Therefore, we term this labor input estimate as quality-adjusted labor input.

Labor Quality Decomposition

Following JGF, equation (1) can be rewritten in a more general form that:

$$\Delta lnL_t^G = \sum_{esca} \bar{v} \Delta lnH_{escat} \qquad (2)$$

where L^G is the quality-adjusted labor input index, *t* is the time subscript, and *e,s,c,a* subscripts denote educational attainment, sex, class of workers, and age respectively, *H* denotes hours

worked of each demographical component. The index of labor quality for the total work force ($Q_{L,t}^{G}$) can be defined as quality-adjusted labor input (L_t^G) divided by total worked hours (H_t) :

$$Q_{L,t}^{G} = \frac{L_t^G}{H_t} \quad (3)$$

If we represent those estimates in the form of natural log the change of quality-adjusted labor input can be decomposed into quality change and hours change components as follows:

$$\Delta lnL_t^G = \Delta lnQ_{L,t}^{G} + \Delta lnH_t \quad (4)$$

Decomposition of education's contribution to quality changes

Following JGF we define a partial index[3] of labor input corresponding to education:

$$\Delta \ln L^e = \sum_e \bar{v}_e \Delta lnH_e = \sum_e \bar{v}_e \Delta \ln(\sum_a \sum_s \sum_c H_{saec}) \quad (5)$$

Where v_e is the cost share of the labor force within the same educational attainment group e, and $\bar{v}_e$ is the average cost shares from two subsequent time periods that can be written as:

$$\bar{v}_e = \frac{1}{2}\left[v_{et} + v_{e,t-1}\right] \quad (6)$$

and

$$v_{e,t} = \sum_a \sum_s \sum_c v_{saec,t} \quad (7)$$

The contribution of education to labor quality, Q^e, is the difference between the growth rates of the first-order education index of labor input and hours worked:

$$\Delta \ln Q^e = \Delta lnL^e - \Delta lnH \quad (8)$$

[3] JGF refers the partial index as "first-order index".

According to JGF the overall labor quality changes can also be represented as the sum of the changes of all four first-order partial indexes—education (Q^e), sex (Q^s), age (Q^a), class (Q^c)—six second-order indexes—Q^{es}, Q^{ea}, Q^{ec}, etc.—three third-order indexes—Q^{esa}, Q^{esc}, and Q^{eac}—and one fourth-order index—Q^{esac}. Since our focus is to identify the contribution of the overall educational attainment changes of the farm labor force to labor quality changes we decompose labor quality changes into educational changes (ΔlnQ^e)and the changes from all other factors (ΔlnQ^o) as shown in the following equation:.

$$\Delta \ln Q^G = \Delta lnQ^e + \Delta lnQ^o \qquad (9)$$

III. Data

The indexes of labor input incorporate data from both establishment and household surveys. Cross-classifications details by characteristics of individual workers are taken from the Census of Population (every 10 years) and the Current Population Survey (CPS) (annual). The major challenge in matrix estimation is the problem of matrix "updating" when we have new information on the controlled totals and yet missing elements from the survey data. Inconsistencies can arise from measurement errors, incompatible data sources, or lack of data. To resolve this problem we adopt the Cross Entropy (CE) approach that minimizes the entropy distance between the prior matrix and the new matrix (Golan, Judge, and Robinson (1994), Golan, Judge, and Miller (1996)) given new information each year. The resulting estimates of. employment, hours worked, and labor compensation are controlled to industry totals based on establishment surveys that underlie the U.S. National Income and Product Accounts (NIPA, BEA) and special tabulation work by BLS derived from CPS. The compensation information not

only covers wages received by the farm labor but also include fringe benefits that reflect the producer cost paid by employers. The time period of this study is 1948-2011.

Golan, Judge, and Robinson (1994) use a cross entropy formulation to estimate the coefficients in an input-output table. They set up the problem as finding a new set of *A* coefficients which minimizes the entropy distance between the prior $\bar{\boldsymbol{A}}$ and the new estimated coefficient matrix. We follow their method in updating employment and hours of work (for hired and self-employed/unpaid labor), and compensation (for hired labor only) matrices of hired and self-employed/unpaid labor in agriculture. For example, given a prior matrix $\bar{E}$of employment (*i* rows of age categories and *j* columns of education categories) we find a new set of E coefficients which minimizes the entropy distance between the prior and the new estimated coefficient matrix.

$$\min\left(\sum_i \sum_j a_{i,j}\, ln \frac{a_{i,j}}{\bar{a}_{i,j}}\right)$$

$$\text{Subject to: } \sum_j a_{i,j}\, y_j^* = y_i^*$$
$$\sum_j a_{i,j} = 1 \; and \; 0 \leq a_{i,j} \leq 1 \qquad (10)$$

where $a_{i,j}$ denotes row *i* and column *j* of the employment matrix and y* are known new row and column sums. The solution is obtained by setting up the Lagrangian for the above problem and solving it. The outcome combines the information from the data and the prior:

$$a_{i,j} = \frac{\bar{a}_{i,j}\exp(\lambda_i y_j^*)}{\sum_{i,j} \bar{a}_{i,j}\exp(\lambda_i y_j^*)} \qquad (11)$$

Where λ_i are the Lagrange multipliers associated with the information on row and column sums, and the denominator is a normalization factor. The employment, hours of work, and the compensation (for hired workers only) matrices are updated to be consistent with the US official

total (from BEA and BLS). The cross entropy procedure was implemented in the GAMS language.

IV. Results and Discussion

Demographic characteristics changes and labor cost structure shifts

Along with the changes in farm labor demographic characteristics the labor cost structure changed as well (table 2). We impute the wage rates for self-employed/unpaid farm workers using the wage rates from their hired labor counterpart with the same characteristics (gender, age, educational attainment). The estimates show that the major spending of the labor cost shifted from workers with 1-8 years schooling years in 1950 to those with 4 years high school educational attainment in 2010. The cost share of the workers with 1-8 years grade school educational attainment reduced from 66% to 10% between 1950 and 2010 while the cost share of workers with 4 years high school educational background increased from 13% to 46% during the same time period. Over time, cost share of the workers with 4 years college degree and above increased more than five times from 3% in 1950 to 16% in 2010.

The cost structure between self-employed/unpaid worker and hired labor also changed. Over time, the total hours worked declined with the hours of self-employed/unpaid worker reduced faster than that of the hired labor (figure 1). As a result, the cost structure between self-employed/unpaid worker and hired worker altered with hired worker's cost share increasing. In 1950 self-employed/unpaid workers accounted for 70 percent of total farm labor cost while in 2010 this portion reduced to 56 percent (table 2).

Decomposition of labor's contribution to agricultural output growth

During the study period U.S. agricultural output grew at 1.49 percent annually. When attributing output growth to its sources of growth the major driving source is total factor productivity (TFP)

growth, contributing to 1.42 percentage points of the annual output growth (table 3).. According to the quality-adjusted labor estimates, between 1948 and 2011, labor input decreased by 78%, at an average rate of -2.4% per year. The contraction of farm labor input has contributed to a reduction of 0.5 percentage points of output growth per annum. Between 1948 and 1968 the considerable labor reduction resulted in the most negative impacts on output growth, ranging from -0.56 to -1.07 percentage points per year (table 3).

When decomposing the growth of quality-adjusted labor into its components—the growth of hours worked and the growth of labor quality—the results show that the decline of labor input is mainly attributed to the decline of hours worked with labor quality increasing over time (figure 2). Between 1948 and 2011 labor hours reduction contributed to -0.58 percentage points to output growth annually while labor quality changes contributed to 0.08 percentage points to the annual growth of output. Labor hours dropped considerably in the first two decades of the study period with labor quality grew much faster than other periods offsetting part of the negative impacts from the hours decline to output growth (table 3). The decrease of labor hours continued contributing to negative output growth in almost all periods. Contrarily, labor quality changes contributed to positive agricultural output growth in almost every sub-period during the study period. The results show that without accounting for the quality changes of labor force the estimated input growth rate could be lower, and thus it could result in a higher growth rate of TFP estimate.

Educational attainment shifts and labor quality decomposition

The overall labor quality changes can be further decomposed into the contribution of educational composition shift (from all labor force) and that from all other characteristics' changes. The lower part of table 3 shows that most of the labor quality changes can be attributed to the

educational attainment structural changes. Among all time periods, education's contribution to labor quality change and to output growth had its highest impacts during the 1958-1978 period, ranging from 0.1 to 0.14 percentage points, along with the substantial increase in the overall labor force's educational attainment. According to Current Population Survey (CPS) (U.S. Census Bureau, 2014), the historical data shows that within the population of 25 years old and over the percentage of people who completed 4 years of high school or more doubled between 1947 and 1979, from 33.1% to 67.7 percent. There is no significant differences between male and female (figure 3). The trend of growth in overall educational attainment slowed during the 1990s and 2000s, and converged to nearly 90 percent level in the 2010s. For example, between 2000 and 2010 the percentage of people who completed 4 years of high school or more within the group of 25 years old and over only slightly increased from 84.1 to 87.1 percent. In the last two decades the continuous decline of total hours worked and slow increase of educational attainment, resulted in a significant amount of negative impact on output growth, ranging from -0.59 to -0.26 percentage points during 1998-2011 period.

Labor productivity changes with alternative labor measures

Labor productivity is measured as real output per unit of labor. It is a popular measure in understanding economic growth or welfare in early literature. It is also a partial productivity index measure that only attributes the output growth to the changes of labor input. The factors driving labor productivity growth could include increase in other input use, technical change, and increase in human capital. We measure labor productivity for the agricultural sector using three labor measures and make comparison. First, labor is measured as total employment. Second,

labor is measured as total hours worked. Third, labor is measured as quality-adjusted labor unit. We present three series of labor productivity estimates in figure 4.

Over time since the total hours worked declined faster than total farm labor employment agricultural output per hour grew faster than agricultural output per person. Quality-adjusted labor unit usually reduced slower than other two labor measures as it has accounted for the increase of labor quality. Therefore, labor productivity based on the quality-adjusted labor measure grew much slower than the other two labor productivity indexes. In 2011 worked hours-based labor productivity, employment-based labor productivity, and quality-adjusted labor based labor productivity were about sixteen times, thirteen times, and eleven times respectively their 1948 levels. This indicates that the farm production has transformed into a highly labor-hours saving production process with increasing human capital contributing to labor productivity.

With competing labor use in other industries and large reduction in farm labor input the agricultural sector has now relied on more other inputs and adoption of technical changes that agricultural TFP growth is higher than most of other industries (Jorgenson et al.).

V. Conclusion

This study employs a Tőrnqvist index approach to construct a quality-adjusted labor index for U.S. farm sector using the volume (hours worked) of 192 demographic components and their corresponding cost shares. To evaluate how educational attainment contributed to the quality changes of farm labor input, we further decompose the labor quality index into an education change component and an other changes component. At the end we construct labor productivity indices based on alternative labor measures. Our results show that between 1948 and 2011 the

substantial decline of total hours worked caused a -0.58 percentage point change of output growth per year. Since labor quality contributed to 0.08 percentage points of output growth that the overall labor input's impact on output growth was -0.5 percentage points per year.

Educational attainment shifts contributed to most of labor quality changes. Its contribution to output growth peaked during 1958-1963, 1963-1968, 1968-1976, and 1973-1978 sub-periods, ranging from 0.1 to 0.14 percentage points. In the last two decades, a slower growth in educational attainment has resulted in smaller labor quality changes and thus has a smaller impact on agricultural output growth. Over time farm output growth has relied more on an increase of other inputs, such as materials (agricultural chemicals, energy, etc.) and capital goods, and TFP growth. We construct labor productivity indexes using alternative labor measures—total hours worked, employment, and quality-adjusted labor index. Results show that agricultural output (in real term) per hour increased much faster than the other two labor productivity measures. Output per unit of quality-adjusted labor index increased much slower than the other two measures due to the increase of labor quality has offset part of the decline in total labor hours.

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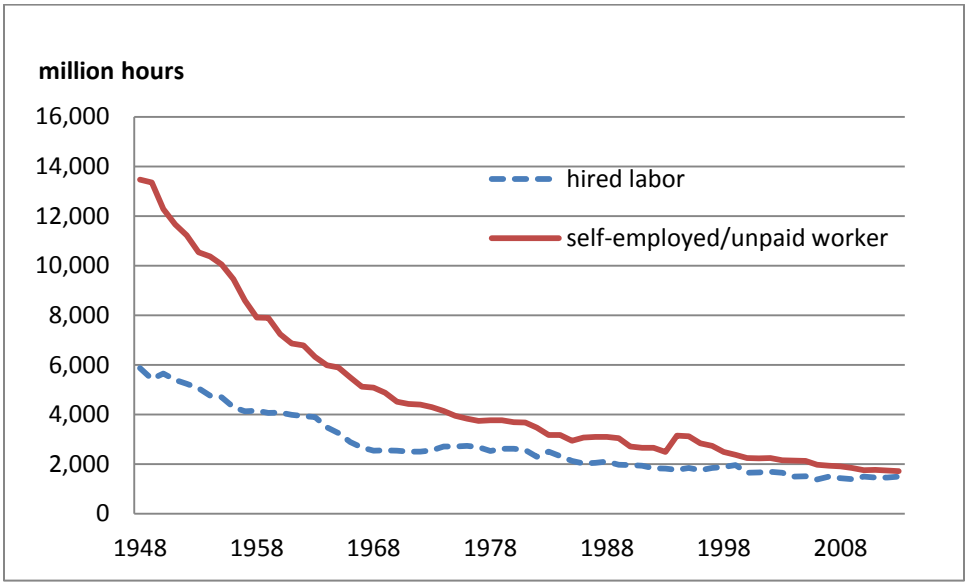
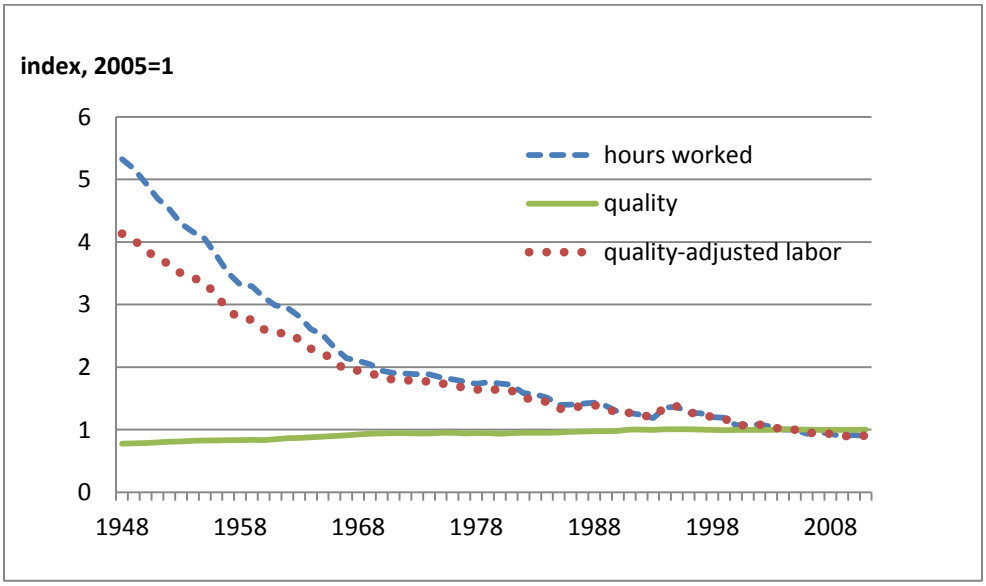
Figure 1. Total hours worked of hired labor and self-employed/unpaid worker (1948-2011)



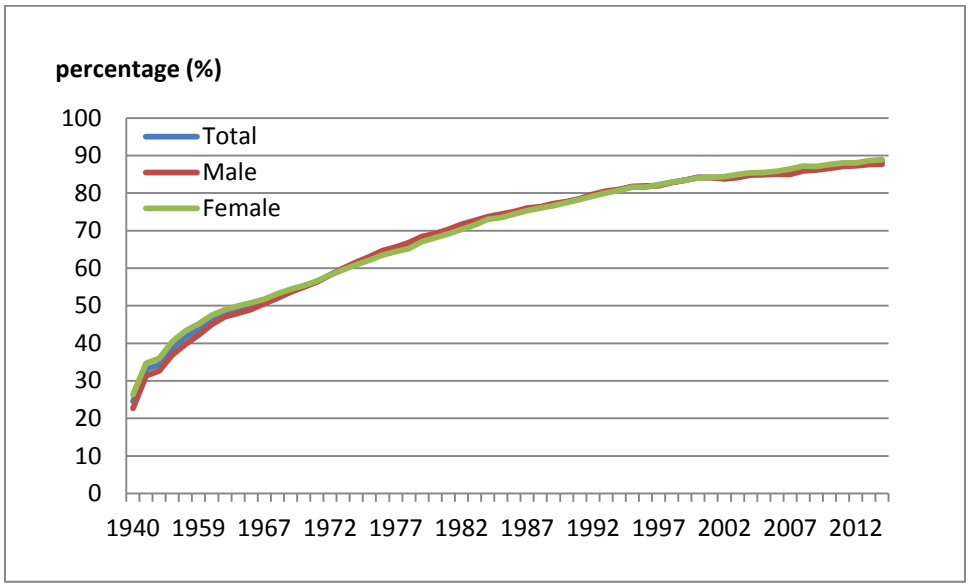
Source: Authors' calculation

Figure 2. Comparison of quality-adjusted labor input, total hours worked, and labor quality indexes (2005=1)



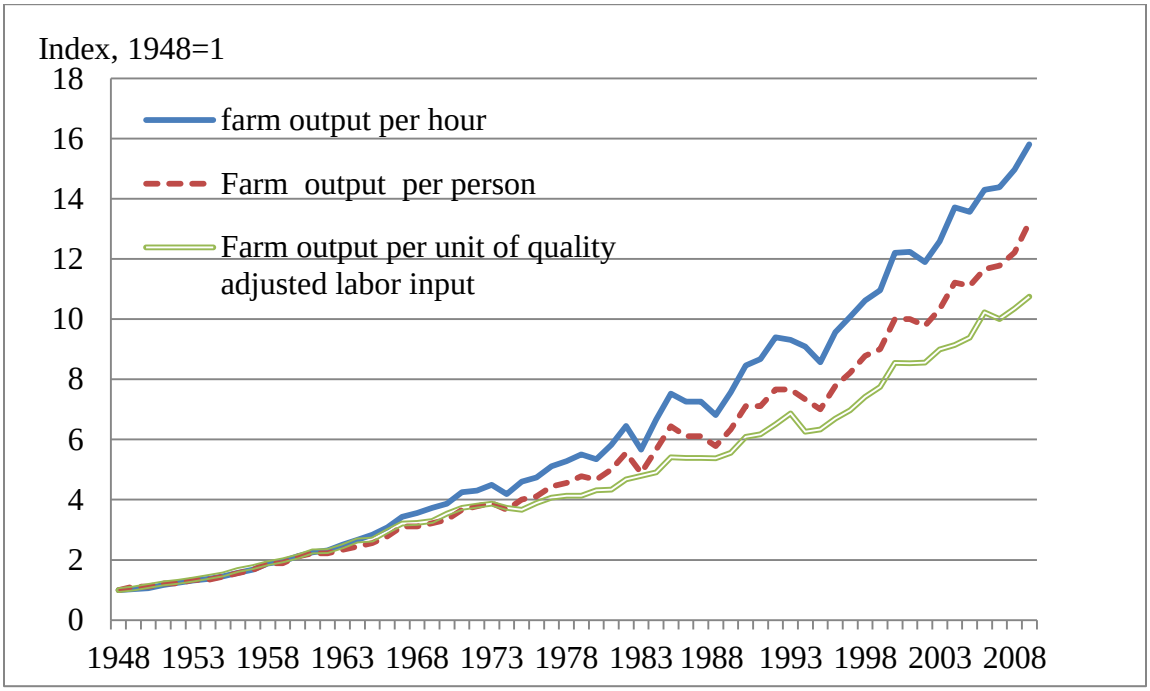
Source: Author's calculation

Figure 3. Percentage of people of 25 years old and over whom completed 4 years of high school or more



Source: U.S. Bureau of Census

Figure 4. U.S. agricultural labor productivity based on alternative labor measures (1948-2011)



Source: Authors' calculation

Table 1 Demographic classifications of labor input

Gender:
(1) Male
(2) Female

Age:
(1) 14--15 years (2) 16-17 years (3) 18-24 years (4) 25-34 years (5) 35-44 years
(6) 45-54 years (7) 55-64 years (8) 65 years and over

Education:
(1) 1-8 years grade school (2) 1-3 years high school (3) 4 years high school
(4) 1-3 years college (5) 4 years college (6) more than four years college

Employment class:
(1) Wage/salary worker
(2) Self-employed/unpaid family worker

Table 2. Labor cost shares by education and employed class

Classification	**1950**	**1980**	**2010**
by education group			
1-8 years grade school	66%	18%	10%
1-3 years high school	14%	13%	10%
4 years high school	13%	45%	46%
1-3 years college	4%	14%	18%
4 years college and above	3%	11%	16%
by class			
Self- employed and unpaid worker	70%	63%	56%
Hired	30%	37%	44%

Source: authors' calculation

Table 3. Sources of Agricultural output growth

		1948-2011	1948-1953	1953-1958	1958-1963	1963-1968	1968-1973	1973-1978	1978-1983	1983-1988	1988-1993	1993-1998	1998-2003	2003-2008	2008-2011
Out[ut growth		1.49%	1.08%	1.97%	2.32%	1.19%	2.68%	1.58%	-0.69%	1.99%	2.50%	2.87%	0.71%	0.92%	-0.26%
Sources of growth															
	Input growth	0.07%	0.89%	0.46%	0.51%	0.10%	0.29%	1.51%	-0.85%	-1.72%	-0.08%	0.98%	-0.53%	-0.43%	-1.42%
	Labor	-0.50%	-0.79%	-1.07%	-0.56%	-0.99%	-0.38%	-0.28%	-0.30%	-0.17%	-0.55%	0.01%	-0.59%	-0.46%	-0.26%
	Land	-0.08%	0.02%	-0.17%	-0.06%	-0.14%	-0.27%	0.02%	-0.09%	-0.08%	-0.07%	0.04%	-0.05%	-0.07%	-0.02%
	Capital	0.01%	0.56%	0.11%	0.02%	0.26%	0.14%	0.34%	-0.01%	-0.81%	-0.31%	-0.23%	-0.04%	0.08%	0.05%
	Materials	0.63%	1.01%	1.56%	1.18%	0.93%	1.01%	1.39%	-0.54%	-0.58%	0.84%	1.14%	0.16%	0.08%	-1.06%
	Total factor productivit	1.42%	0.19%	1.51%	1.81%	1.09%	2.39%	0.07%	0.16%	3.71%	2.58%	1.89%	1.24%	1.35%	1.16%
Decomposition of labor's contribution to output growth															
	Labor	-0.50%	-0.79%	-1.07%	-0.56%	-0.99%	-0.38%	-0.28%	-0.30%	-0.17%	-0.55%	0.01%	-0.59%	-0.46%	-0.26%
	Hours	-0.58%	-1.02%	-1.19%	-0.72%	-1.28%	-0.43%	-0.29%	-0.31%	-0.25%	-0.63%	0.01%	-0.59%	-0.47%	-0.27%
	Quality	0.08%	0.22%	0.12%	0.16%	0.29%	0.04%	0.01%	0.01%	0.08%	0.08%	-0.01%	-0.002%	0.012%	0.009%
Decompsition of labor quality															
	Education	0.07%	0.09%	0.07%	0.14%	0.19%	0.13%	0.10%	0.09%	0.06%	0.06%	-0.001%	0.002%	-0.01%	0.002%
	Others	0.01%	0.13%	0.04%	0.02%	0.10%	-0.09%	-0.09%	-0.07%	0.02%	0.02%	-0.01%	-0.004%	0.02%	0.01%

Sources: authors' calculation