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# Embodied-Technical Change of Farm Tractors in U.S. Agricultural Productivity Analysis: What Does the Hedonic Price Tell Us?[1]

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[1] The views expressed herein are those of the authors, and not necessarily those of the Economic Research Service or the U.S. Department of Agriculture.

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# Embodied-Technical Change of Farm Tractors in U.S. Agricultural Productivity Analysis: What Does the Hedonic Price Tell Us?

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**Abstract**

This study employs new data and a hedonic function to estimate the quality-adjusted price and quantity for farm tractors over the 1950-2011 period. The estimated hedonic prices for tractors are lower than the BLS' tractor price index in most time periods. The lower prices result in a higher estimate of the tractor stock and service flow, which reflects an increase in embodied technical change of farm tractors. After replacing the BLS deflator of tractor investment with these hedonic estimates, average annual TFP growth dropped by 0.13 percentage points over the 1991-2011 period compared with the current USDA's productivity estimate. These changes can be attributed to the contribution from embodied technical change in farm tractors over this period. The findings show the potential importance of input quality adjustment and can help to explain the sources of productivity growth.

**Key words:** Hedonic price, farm tractor, total factor productivity (TFP)

**JEL:** O3, O4, Q1

## I. Introduction

Since George Stockton Berry built the first self-propelled combine in 1886, and John Froelich built the first gasoline/petrol-powered tractor in 1892, the evolution of farm machinery has transformed and enhanced farm operation performance by increasing speed, scale, efficiency and reliability. When purchasing farm machinery, farmers have benefited from embodied technical change that promotes efficiency and productivity in farm production. According to USDA's productivity accounts, over the 1948 to 2009 period, agricultural output grew at an average 1.63% annual rate with only a slight growth in inputs averaging only 0.11% per annum (USDA, 2012). The result is that total factor productivity (TFP) growth accounts for most of the growth in U.S. agricultural output, increasing at an average 1.52% annual growth rate. While estimates of TFP capture the change in output growth that cannot be explained by input growth, Griliches and Jorgenson (1966) suggest that we also need to understand or explain sources of productivity growth. If embodied technical changes or quality changes of various inputs could be quantified then the residual could be attributed to disembodied technical change on the output side.

One way to account for embodied technical change in farm machinery is to construct indices of quality adjusted price and quality adjusted quantity for machinery investment based on hedonic measurement. A hedonic price index was first developed by Court (1939) in a study of automobile characteristics. Since Griliches readdressed this issue in 1961, hedonic measurement has been widely used in studies that considered quality adjusted price measurement, such as Rosen (1974), Nelson, et al. (1994), Triplett (1987, 1989), and Fernandez-Cornejo and Jans (1995). Although there have also been studies using the hedonic approach to construct quality adjusted tractor prices, there has been no study applying the quality adjusted tractor prices in a productivity analysis to evaluate the role of embodied technical change in agricultural output growth.

The purpose of this research is three-fold: first, to understand changes in farm tractors over time, examining the last six decades; second, to construct quality adjusted price and quantity indices for farm tractors; and third, to decompose the output growth into contributions from inputs and total factor productivity, with a special focus on the changes in capital growth using alternative estimates of tractor prices. This can help us understand embodied-technical changes through the purchase of farm tractors and their impacts on U.S. agricultural productivity measures.

## II. Methodology

*The Hedonic approach*

Rosen (1974) established a theoretical hedonic framework by relating the hedonic function to utility and production functions. Under this framework, a good or a service can be viewed as a "bundle" of characteristics that contribute to output or utility derived from its use. Therefore, the price of a good or service is decided by the quantity and value of the characteristics "that are bundled in it". Since the price for each characteristic is not observable, we need to define a hedonic price function using product characteristics as the regressors.

There are two major ways to construct the hedonic price for tractors. One is to pool the time series and cross-section data of all types of tractors together and to use time dummies along with characteristics variables to conduct econometric estimates. The weighting scheme is based on sale values. The coefficients of the time dummies are used to construct the quality-adjusted price index, and the coefficients of the characteristics are their implicit prices. The other method is to run hedonic regressions for each specific tractor model with time dummies and characteristics bundled in that specific model. The estimated hedonic prices for each specific model are then used to construct a price index based on the Laspeyres or Paasche index approach. In this study we use the former approach due to limitations in our data. Also, there is one advantage to using this approach--since the weights change from year to year, we are able to capture the composition shift in tractor sales over time. Following Griliches (1961), Rosen (1974), and Triplett (1991), we assume a hedonic tractor price function with a general form:

$$p_{it} = \boldsymbol{\beta}' \boldsymbol{x}_i + \boldsymbol{\gamma}' \boldsymbol{z}_{it} + \varepsilon_{it} \quad (1)$$

where $p_i$ represents a hedonic price of farm tractors; $\boldsymbol{x}_i$ is a vector of quantities of the characteristics embodied in each farm tractor—including engine size (horsepower), and transmission type (2WD or 4WD), and $\boldsymbol{z}_{it}$ is a vector of time dummies. While Power-take-off (PTO) information is available in recent years, it was not included in earlier data. Therefore, we do not include PTO in the regression model. Gibbons et al. (1892) have shown that among the six major characteristics—Engine size, Transmission, PTO, Hydraulies (HYD), Cab, and Steering, only Engine size (Engine power), and transmission type (4WD) are significant in all regressions. They argue that the insignificance of other characteristics may be due to the serious multicollinearity problems.  This may justify the use of only horsepower and transmission type in our estimation. Among other tractor hedonic price studies, Gordon (1990) and Fettig (1963) have made adjustments for the value of attachments and accessories in their studies. Since our data has separate observations for tractors and attachments we do not need to make the adjustment. While Fettig and Gordon have also included diesel as a characteristic variable in their estimation other than horsepower, we do not include this variable due to the lack of diesel information in our data.

*Measurement of capital service flow*

The current capital estimates in USDA's productivity accounts include seven categories of capital assets—land, buildings, tractors, trucks, automobiles, other machinery, and inventory. In order to identify the role of embodied technical change introduced by tractors in U.S. agricultural productivity analysis, we need to evaluate the impact of using hedonic tractor prices in TFP estimates. The USDA's productivity measurement requires measures of capital input and service prices. We first construct two series of real tractor investment data using hedonic tractor prices and BLS tractor prices. Following USDA's current approach, we apply the perpetual inventory method to construct tractor stocks using two series of real tractor investment.

Under the perpetual inventory method, capital stock at the end of each period, $K_t$ , is measured as the sum of all past investments, each weighted by its relative efficiency $d_\tau$:

$$K_t = \sum_{\tau=0}^{\infty} d_\tau \, I_{t-1} \qquad (2)$$

where $d_\tau$ is approximated by hyperbolic efficiency function,

$$d_\tau = (L-\tau)/(L-\beta\tau), 0 \le \tau \le L \qquad (3)$$

$$d_\tau = 0, \tau \ge L,$$

$L$ is the mean service life of the asset and it is assumed that the underlying distribution is the normal distribution truncated at points two standard deviations above and below the mean service life. $\tau$ represents the asset's age, and ß is a curvature or decay parameter and is assigned a value of 0.5, assuming that the decline in efficiency is uniformly distributed over the asset's service life. The implicit rental price of capital, c, is estimated as

$$c = \frac{r w_K}{1-F} \qquad (4)$$

$w_K$ is the price of investment goods, *r* is the real rate of return and is calculated as the nominal yield on investment grade corporate bonds less the rate of inflation as measured by the implicit deflator for gross domestic product. An ex ante rate is then obtained by expressing observed real rates as an ARIMA process. F denotes the present value of the stream of capacity depreciation on one unit of capital. We then calculate F holding the required real rate of return constant for that vintage of capital goods. In this way, implicit rental prices are calculated for each asset type (details can be found in Ball et al. (2008)).

*Measurement of Total Factor Productivity*

The USDA's TFP estimates are formed from Törnqvist indexes of outputs and inputs. A sector's total factor productivity (TFP) growth over some period is defined as:

$$\ln\left[\frac{TFP_t}{TFP_{t-1}}\right] = \sum\left[\frac{R_{it}+R_{i,t-1}}{2}\right]\ln\left[\frac{Y_{it}}{Y_{it-1}}\right] - \sum\left[\frac{W_{jt}+W_{j,t-1}}{2}\right]\ln\left[\frac{X_{jt}}{X_{jt-1}}\right] \qquad (5)$$

where the $Y_i$ are output indexes, the $X_j$ are input indexes, the $R_i$ are output revenue shares, and the $W_j$ are input cost shares (details can be found in Ball, Wang, and Nehring (2012)).

## III. Data

For the 1991 to 2011 period, we draw on prices, quantities, and characteristics of farm tractors mainly from AEM unpublished data. For the pre-1991 period, which allow us to construct a longer series of hedonic price and capital stock for farm tractors, the data on prices, quantities, and characteristics of farm tractor have been patched together from two main sources: Bureau of the Census, Industry Division, Current Industrial Reports; and reports from the Association of Equipment Manufacturers (AEM). Relevant Current Industrial Reports with different levels of detail are continuous for 1948-1991. The "Farm Machines and Equipment" series (MA-35A) ran from 1948 to 1968, when the series became "Tractors" (M37A-08) and later "Farm Machinery and Lawn and Garden Equipment" (series M333A). AEM has been located in Chicago, Illinois for most of its history and draws data from over 157 companies[3] including 34 tractor, combine and farm equipment manufacturers. From 1948-1963, their reports were published under the "Farm Equipment Institute," from 1964-1989, the "Farm and Industrial Equipment Institute," and from 1990-2001, the "Equipment Manufacturer's Institute," before becoming AEM, the present name of the trade association. These reports provide the only unit sales data available at the state level. Capital investment expenditures are drawn from USDA-ERS farm income data and productivity accounts. The time period for this study is 1950 to 2011.

## IV. Changes in U.S. Farm Tractor Sales

Tractors and combines are the most important pieces of self-powered farm equipment used in US agricultural production. Tractors were originally designed to

[3] This was the number of companies named as "key technical council liaisons" in 2000.

mechanize agricultural tasks, such as tillage, and by towing various attachments tractors have provided more functions in farm production. Between 1948 and 2008, the number of annual units sold for these two types of machinery have shown a near-inverse relationship to each other. Between 1948 and 1951, 8,000 to 11,000 self-propelled combines were sold in the US each year, and around 400,000 tractors, as shown in the 1950 total row at the bottom of table 1. Peak annual unit sales of combines took place between 1973 and 1979 with 32,000 to 35,000 units sold each year. Having dropped every year since 1973, annual unit tractor sales reached their lowest levels in 1993 with only 68,500 units sold in all power categories. By 2004, tractor sales had risen back to 205,000 units which was higher than they had been since 1955.

(Insert Table 1 here)

The U-shaped pattern of annual tractor units sold masks compositional changes in the sizes of tractors being purchased. Three-quarters of the tractors sold between 1948 and 1951 were under 40HP (top row table 1), and sales of this small power size remained at fairly high levels through 1960. The under-40HP group became the largest unit sales category again in 1982, and after 1992 grew through 2004 as can be seen on figure 1. This re-emergence of smaller equipment represented a shift from their use as row-crop field operations equipment in the 1950s and 1960s to utility vehicles in the 1990s, performing farm functions that had previously been carried out using pick-up trucks. The high point for annual units sold of over-100 HP tractors came during the same peak period for combines in the 1970s and early 1980s as this size category became the primary row-crop and field operations equipment. After 1983, the over 100 HP category remained between 18,000 and 30,000 annual units through the end of the sample. These compositional shifts can be combined with size category price changes to determine hedonic changes in machinery characteristics that might be used to reflect technical changes in farm machinery form and function.

(Insert Figure 1 here)

## V. Hedonic Tractor Prices and Total Factor Productivity Estimates

*Quality-adjusted prices of farm tractors*

We treat the horsepower variable two different ways in our hedonic estimation. One is to include horsepower as one quantity variable (Model 1), and the other is to use twenty five horsepower dummy variables (there are twenty six horsepower categories in our data, one horsepower dummy variable is excluded in the estimation) in the regression model (Model 2). The benefit of the latter is that it allows the flexibility of changing marginal values from one horsepower category to the next as there may not exhibit a specific form or pattern for the value of horsepower. If the value of each category of horsepower represents the productivity or efficiency of that specific model, we can see in figure 2 that based on the horsepower fixed effects estimates the value of horsepower is nonlinear. It increases most sharply between 100 HP to 250 HP. Figure 3 demonstrates three tractor price series—estimates from Model 1, Model 2, and BLS—from 1991 to 2011. The three series move close to each other before diverging in 2004 and reuniting in 2010. In general, Model 2 presents the lowest tractor price indicating the estimate may have reflected more quality changes in tractors over time. The lower prices from hedonic estimates will result in a higher estimate of quality-adjusted tractor input and service flow. The increase in the "quantity" of the capital service flow reflects an increase in embodied technical change through farm tractors.

(Insert Figure 2 and Figure 3 here)

*Impacts of quality-adjusted tractor prices on TFP estimates*

In the productivity analysis we apply the hedonic price series from Model 2 to adjust for quality changes in farm tractors over time. After taking the composition shift in tractor characteristics into account, the quality-adjusted price changes were lower than the un-adjusted inflation rates. The impact of this adjustment caused the annual total factor productivity growth rate to drop by 0.01 percentage points from 1950-2011 (table 2). Yet, in figure 4 we can see that the adjusted TFP series using hedonic tractor prices is much lower than the TFP series using the BLS price index in earlier years. When we focus on more recent years, such as 1990 to 2011 (table 2), annual TFP growth drops by 0.13 percentage points, attributable to the embodied technical change in tractors. And again, if we only look at the period 2000 to 2011, the annual TFP growth drops by 0.04 percentage points. The different impacts by looking at alternative sub-periods may reflect different speeds in embodied technical change as well as the composition shift among different types of tractors purchased. The results can help us to explain more about the sources of growth, as Griliches and Jorgenson suggest.

(Insert table 2, figure 4 here)

## VI. Conclusion

This study employs new data and a hedonic function to estimate the quality adjusted price and quantity for farm tractors over the 1950-2011 period. The hedonic price estimates from this study are lower than the BLS estimates for most of the period. The lower prices will result in a higher estimate of tractor stock and service flow, which reflects an increase in embodied technical change of farm tractors. After replacing the BLS deflator of tractor investment with new hedonic estimates, average annual TFP growth drops by 0.13 percentage points from 1991 to 2011. The changes can be attributed to properly accounting for embodied technical change in farm tractors over this period. These findings show the potential importance of quality adjustment in productivity analysis and help to explain the sources of growth. Yet, there are still limitations and discrepancies in the data. Through continued improvement in the underlying data and conducting studies on quality changes for other farm machinery, we can better understand overall embodied technical change in farm machinery over time.

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**Table 1 Conposition shifts of U.S. farm tractors**

| HP | 1950 | | 1991 | | 2011 | |
|---|---|---|---|---|---|---|
| | total units | shares | total units | shares | total units | shares |
| <40 | 301501 | 76% | 35672 | 38% | 84325 | 50% |
| 40-80 | 93160 | 24% | 24732 | 27% | 31768 | 19% |
| 80-120 | 0 | | 10334 | 11% | 24240 | 14% |
| 120-160 | 0 | | 10787 | 12% | 5020 | 3% |
| 160-200 | 0 | | 7703 | 8% | 4872 | 3% |
| >200 | 0 | | 4064 | 4% | 17389 | 10% |
| Total | 394660 | | 93292 | | 167614 | |
| Note 1: the number of 1950 is an average of 1948-1951 | | | | | | |
| Data source: AEM and authors' calculation | | | | | | |

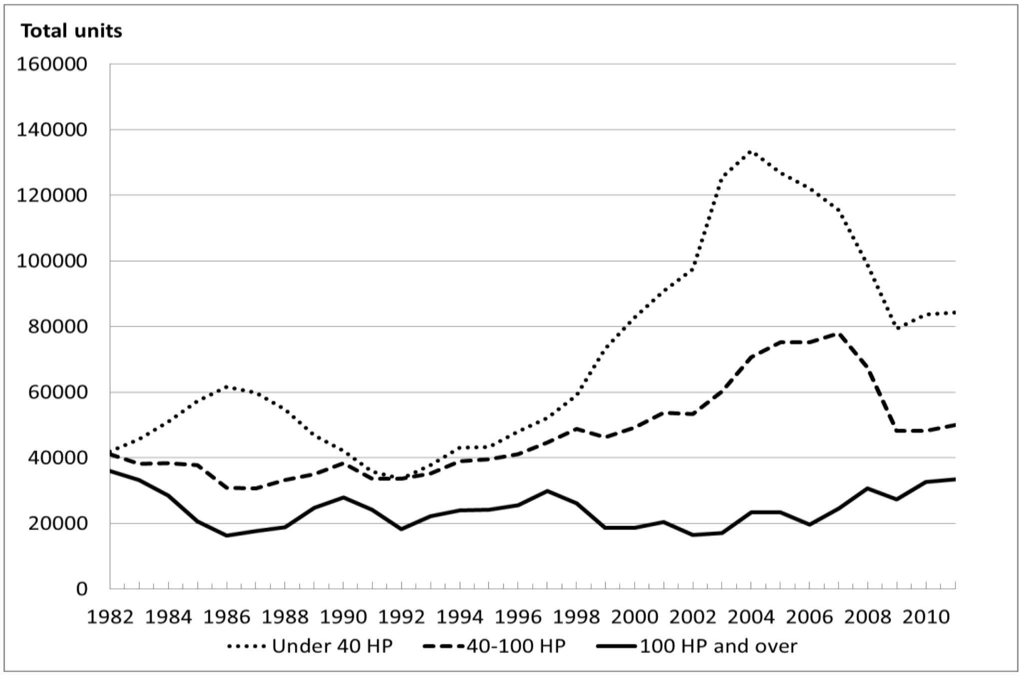
Sources: AEM, and authors' calculation

**Table 2 Impacts of alternative tractor prices on TFP estimates**

| period | Output growth | input growth | adjusted input growth | TFP | adjusted TFP | TFP differences |
|---|---|---|---|---|---|---|
| 1950-2011 | 1.57% | 0.05% | 0.06% | 1.52% | 1.51% | -0.01% |
| 1990-2011 | 1.09% | 0.06% | 0.19% | 1.03% | 0.90% | -0.13% |
| 2000-2011 | 0.40% | -0.21% | -0.17% | 0.61% | 0.57% | -0.04% |

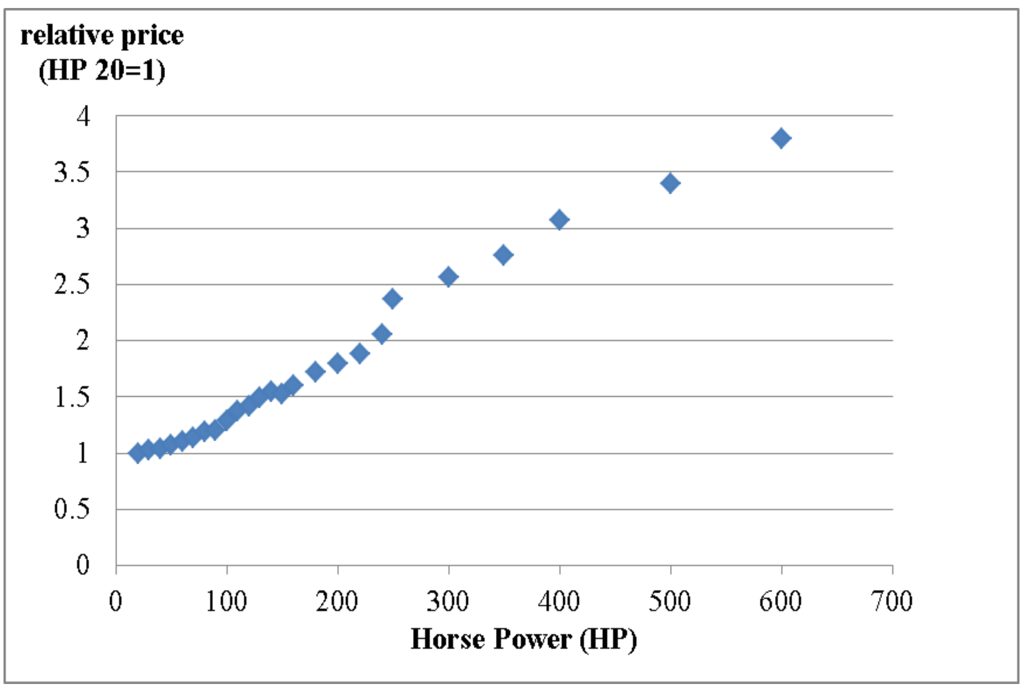
Sources: Economic Research Service, and authors' calculation

**Figure 1 Sales of tractors by horsepower (HP) categories over time**



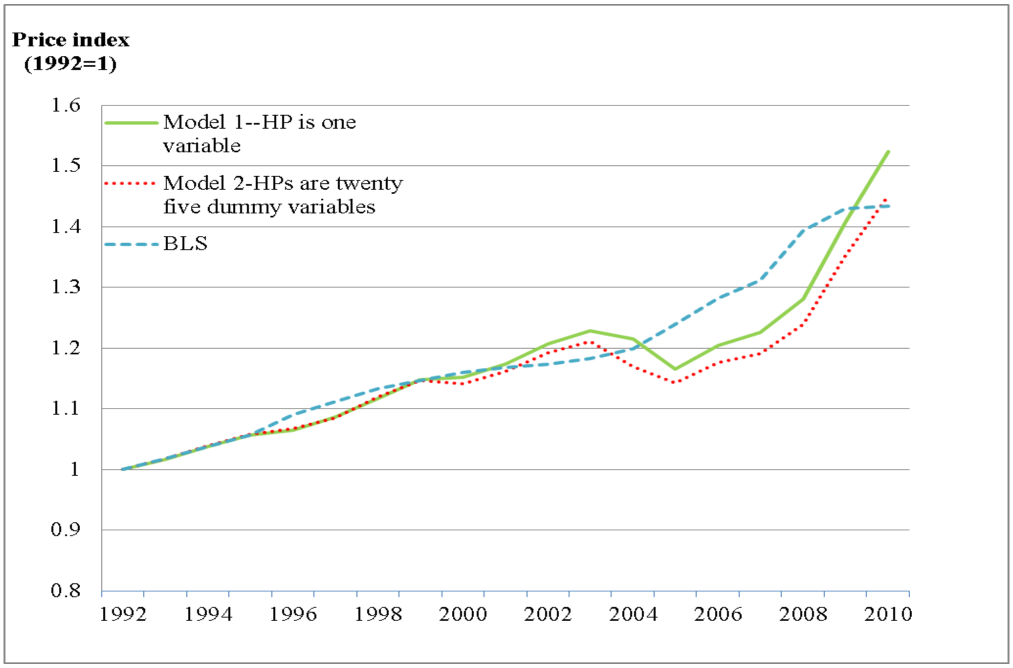

Sources: AEM and authors' calculation.

**Figure 2. Relative tractor prices by HP**



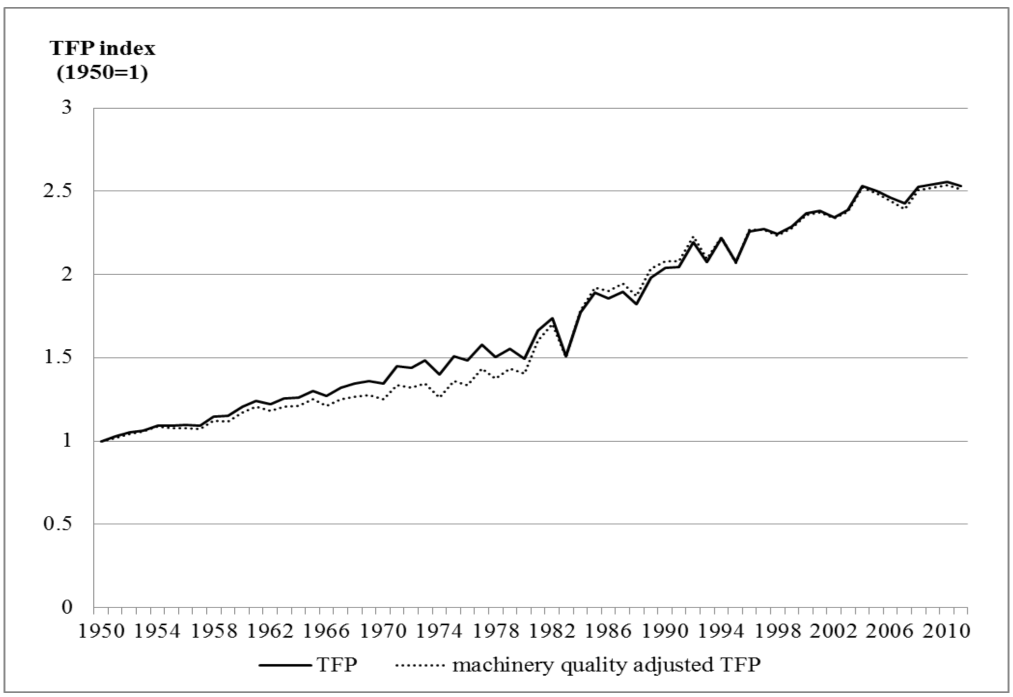

Data Source: by Authors

**Figure 3. Tractor prices comparisons**




Sources: BLS and authors' calculation

**Figure 4. Machinery quality adjusted TFP vs. unadjusted TFP (1950-2011)**




Source: Economics Resaerch Service and authors' calculation.