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A Chronological Study of Total Factor Productivity and Agricultural Growth in U.S. Agriculture

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1. Introduction

With regards to Total Factor Productivity (TFP) in agriculture, voluminous literature has been published that emphasize on explaining the variations in agricultural productivity that can be evidently attributed to factors other than traditional inputs such as land, labor and capital. Solow (1957) was the first to propose a growth in overall output level that does not completely correspond to the variations or growth in factor inputs. Agricultural productivity measurement or mathematical computation of agricultural TFP generally employs two empirical approaches: The Parametric and the Non-Parametric. The most traditional one is the Parametric approach which has a strong conceptual connection with the constitution of Divisia Index of productivity which fundamentally advocates quantifying productivity trends by observing changes in both output and input indexes. Richter (1952) extensively discussed the economic interpretation of the Divisia Indexes of TFP and devised various ways to construct output and input indexes. The Divisia Index Method is associated with the Social Accounting Method initially supported by Solow and contends that growth rate of TFP is ideally the differences between growth rates of real output and real factor inputs. Now as observed by Abramovitz (1962), such difference encapsulates the effect of "costless" technological advancement, managerial efficiency or other aspects of human capital in the production process. Under the Neoclassical Production Theory, such impacts are reflected by shifts in Production Function as "costless" advances in technical endowments basically refers to output expansion with factor inputs namely land, labor and capital being held constant. Alternatively output growth can also be represented by shifts along the production function meaning increase in employment of scarce resources (factor inputs) with alternative uses. The Social Accounting Method of calculating TFP gained prominence with Diewert (1976) as the Divisia Index has been proved to be consistent in aggregation and superlative for a linear homogenous trans-logarithmic production function. On the other hand, Chavas and Cox (1988) used a Nonparametric Approach, which is the other approach to calculate TFP to analyze the technical progress that is measured by the

changes in output not attributable to variations in input growth. The concept of parametric analysis of productivity suggests that technical progress in production process should be measured either through cost minimization or profit maximization not attributable to changes in input prices or output level (output prices). Accordingly, this dual approach of producer's optimization problem intends to reflect the residual measure of productivity that does not correspond with input expansion or fluctuations in input prices or output prices. Therefore, there is a need to distinguish between the contributions of technical progress in productivity growth and those of return to scale and input prices (Grichiles).

However, the limitations of both the Social Accounting Method and Nonparametric Approach lie in their respective empirical inaccuracies and failure of these methodologies in comprehensively addressing the explanation of changes in TFP. For example, Jorgensen and Griliches (1967) points out that any error in the estimation of real output or product and real factor input indexes or the respective output and input price indices can possibly result in erroneous estimation of TFP. Thus under this approach TFP estimation is very much vulnerable to any measurement error or biases. Furthermore, as the operational or theoretical definition of TFP suggests, Social Accounting Method or the Divisia Index does not really specifically uncover the real sources of TFP or fails to distinctly identify what is exactly meant by technical progress in the production process or what are the factors that truly contribute to TFP growth other than traditional factors of production (Chand, Kumar and Kumar, 2011). Similarly, under the Nonparametric Approach, it is not always possible to distinguish between the contributions of technical progress and the returns to scale effect and changes input or output prices. Much of the changes in TFP are in fact wrongly merged with changes in input prices and scale effects. Sato (1970) has demonstrated that under certain conditions, the effects of technical progress are inseparable from the scale effects under the neoclassical theory of Production Function. Similarly, it is difficult to distinctly identify the sources of technical progress even under this approach and much of the real sources of TFP often remain elusive. This problem constitutes the underlying foundation of this paper. The objective of this paper is to examine the real sources of TFP by employing a purely econometric approach based on a time series study of factor productivity trend in

US Agriculture from 1970 to 2004. Now, any critical analysis of the two aforementioned methods of TFP estimation is beyond the scope and capacity of this paper and neither has it intended to undermine any of these methodologies. Instead, this paper uses an independent econometric approach completely isolated from any conventional study of TFP, which are more or less based on mathematical definition of TFP.

2. Background of Productivity Growth in US Agriculture

In the process of examining the productivity trend in US Agriculture for the last 35 years, this paper intends to address the major sources of TFP in the agricultural sector as a whole. The major emphasis is directed towards applying a purely econometric approach devoid of any direct mathematical derivation of TFP as signified by both Social Accounting Method and Nonparametric Approach. Several previous studies on US agricultural productivity growth have attempted to determine the TFP by observing the growth rates in output and major factor inputs. Ball, Schimmelpfennig and Wang (2013) has examined the TFP growth (TFPG) trend in US Agriculture from the period 1948 to 2009 and found that despite a pronounced contraction in labor input at an average annual rate of 2.51% and a feeble growth rate in intermediate input at 1.43% per year, output grew at average annual rate of 1.63%. During the same time period the study documents a sharp rise in chemical and energy inputs at more than 2% per year respectively. Wang (2014) shared a very similar observations which shows that according to USDA-ERS productivity statistics, overall US Agricultural output growth rate reached at an average annual rate of 1.63% from 1948 to 2009 with a corresponding overall input or factor growth rate of 0.11% per year accompanied by a notable TFPG rate of 1.52% per year for the period of study. Table 1 represents the average annual growth rates of the individual sources of output growth in US agricultural sector as a whole .Among the traditional inputs, labor growth and land use declined sharply by 78% and 27% respectively and a massive increase in the use of intermediate inputs (pesticides, fertilizers, chemical inputs, fuel, energy inputs etc.) by nearly 140% implying the substitution of those inputs for other inputs. Increased use of intermediate and substitute inputs such as high quality variety seeds, agricultural chemicals and advanced farm machineries have led to quality improvements and better organization of production methods contributing to efficient use

of new farm technologies (White and Hoppe, 2012). All of these factors have evidently contributed to a conspicuously high growth rate of TFP explaining to a considerable extent the role of TFP in a highly positive output growth rate in US agriculture for the last several decades. In addition, a higher level of extension activities and agricultural research and development spending (R & D spending) at both private and public levels can also impel technological spillover and TFPG (Ball et al., 2013). The sources of high TFPG can also be a partial outcome of agriculture and trade policies and the regulatory environment through public policy programs (O' Donoghue, 2011). Based on the previous literature on the sources of TFPG and the output growth in US agriculture, this paper conducts a time series study of the TFP trend in US agriculture from 1970 to 2004 with the view to find out the most significant precise sources of TFPG during the desired period of study and consequently propose any future implications that the results might carry in maintaining long term food security and agricultural sustenance.

3. Methodology and Data Description

An annual time series regression has been conducted on TFP index for US Agriculture from 1970 to 2004 against eight major independent variables. These variables include total Agricultural Research and Development funding for the intended time period of study, index of fertilizer consumption, index of pesticide consumption, index of energy input use, index of chemical inputs, percentage of the population 25 years and over who have completed high school or college since 1970 to 2004, overall public sector funding or disbursement on new highway constructions and maintenance of existing ones and number of tractors per 100 sq.km of arable land. Now TFP evidently can be affected innumerable factors such as research, agricultural extension, human capital, mechanized farming practices, intensity of cultivation, changes in soil condition, balanced composition of plant nutrients and many other unobservable or undetectable determinants. The methodology attempts to incorporate as much of these issues of occurrences but however might have omitted some key variables such as overall agriculture extension stocks, cropping intensity, ratio of soil nutrients due to paucity of data and missing data during the time period of the study as well as years prior to that. This ideally explains the confinement of the study from 1970 to 2004 and even data for

the variable in the study has been difficult to trace back to the time period prior to the start of the study period. As an indication of infrastructural spending, overall public sector federal fund disbursement on highways has been used as any palpable infrastructural development would conceivably facilitate the supply chain distribution of commodities and processed agricultural goods. Consumption and use of pesticides, chemical and energy inputs constitute the intermediate inputs employed in the production process that are not essentially considered as a part of the traditional capital inputs. Number of tractors used per 100 sq.km of arable land for the period of study reflects the mechanization of farming practices as with time the sector witnessed the introduction and deployment of increasingly mechanized tractors. Furthermore based on findings by Ball, Schimmelpfennig and Wang (2013) that are much more exclusively connected to historical study of the sources of TFP in US agriculture, more emphasis has been given on intermediate input use that has been evidently been observed as one of the foremost sources of TFP in sectoral output growth aside from agricultural research funding. Following Evenson, Pray and Rosegrant (1999), who have conducted a similar cross-sectional pooled time series analysis for Indian Agriculture, agricultural R and D funding has been used as an indicator of research stock variable that is also expected to affect TFP significantly based on previous results. As an indicator of the impact literacy development or human capital on TFP, the population percentage of 25 years and over who have completed at least high school or obtained a college degree has been used. Although specific data on rural education and literacy could not be found, this explains why the model uses national data as a proxy. TFP index has been constructed using the Divisia Index from the total output and input indices. Accordingly the specification of the regression equation has been stated as:

Model 1: $lnTFP = \alpha + \beta_1\ lnTotalAgRsrchFndng + \beta_2 lnIndxofFertCon + \beta_3 lnIndxofPestCon + \beta_4 lnEnergyIndx + \beta_5\ lndxChemIn + \beta_6 lnEducation + \beta_7 lnhighwayfin + \beta_8\ lnAgmachineryTractor + \varepsilon$

The data on total agricultural R & D spending, indices of fertilizer consumption, pesticide consumption, energy inputs and chemical inputs have been collected from the data set on productivity published by United States Department of Agricultural, Economic Research

Services (USDA, ERS) and particularly, the agricultural R & D funding has been extracted from a collaborative publication by ERS and National Science Foundation (NSF). The percentage of people 25years and over who have completed high school or college has been collected from the reports on "Educational Attainment in the United States: 2009" published by the United States Census Bureau (USCB) and the data on number tractors per 100 sq.km of arable land has been found on World Bank databank on respective countries. The input and output indices are being listed under Findings, Documentation and Methods section of USDA, ERS productivity data and the TFP Index has been computed by using the Divisia Index for each of the observations.

The methodology has been divided into two models. The first model is intended to highlight the main sources of the TFP for the time period under consideration through OLS Time Series Regression estimation and the second model decomposes the estimated TFP index into the translog Neoclassical production function and excluding the assumption of Constant Returns to Scale (CRS) to register the impact of TFP on total agricultural output index. The TFP in Model 2 represents the residual measure or the stochastic estimation of the translog production function and the objective is to explain the variation in the output index that is ideally not explained by changes or growth in traditional inputs such as labor and capital. Now theoretically, Neoclassical production function encapsulates the effect of technical progress and the derivative of the overall output with respect to time gives an estimation of the productivity growth but those mathematical derivations does not essentially reflect TFP as sources of TFP transcends any major changes in technological advancements in the production process and includes several other attributes that constitute the stochastic error term of the Neoclassical production function. Model 2 presents the translog production function where TFP index has been added as an additional variable in addition to labor and capital indices (excluding land). Both annual labor and capital indices have been found on the USDA ERS productivity dataset and all the data used for labor and capital indices are farm level. Again OLS Time series regression has been used to estimate the total annual output index against three major variables from 1970 to 2004. The specification of the regression equation for Model 2 is stated below:

Model 2:

$$lnOutputIndx = \alpha + \delta_1 lnCapitalIndx + \delta_2 lnLaborIndx + \delta_3 lnTFPIndx + \varepsilon$$

The main objective of the econometric model is to estimate the impact of TFP on overall output index and identify the most important sources of TFP that in an intrinsic process also contribute to output growth.

4. Major Sources of TFP and Discussions

Time Series estimation has been undertaken assuming a logarithmic functional form equation and using a fixed effect approach for the annual time series national level data with corrections for auto correlation and unit root. Johansen test has been conducted to test for cointegration.The initial estimation using the 35 observations from 1970 to 2004 yielded some serious problems pertaining to high degree of multicolinearity for 4 explanatory variables including agricultural research and development funding, chemical input index, pesticide consumption index and fertilizer use index. Unit root was also present for TFP index, agricultural R & D funding, index for pesticide consumption, index for fertilizer consumption and agricultural tractors as reflected by the Augmented Dickey Fuller (ADF) test using 9 years lags. The number of lags used in the ADF test has been selected based on the rule of thumb for determining p_{max} suggested by Schwert (1989).To amend for these estimation errors, time series regression has been re-conducted by using the first year lags for all the variables.

Figure 2 presents the results for regression estimates for TFP Index. Now first of all, the estimations for pesticide consumption and chemical inputs are highly significant with a statistical significance of 1% using the t test. The index for fertilizer consumption is significant at 5% level. The coefficients for energy input signify a positive but relatively weak impact of energy input use on TFP, which is also significant at 5% level. As reflected by coefficient estimates, the pesticide consumption index and the chemical input index have a quiet considerable impact on overall TFP for the time period considered. Fertilizer consumption also has a comparatively significant impact on

TFP. On the contrary to much of the empirical speculations and observations by previous literature on TFP estimation, the coefficients of agricultural R & D spending are non-significant but still exhibit a notable effect on TFP for the time period under consideration. These results collectively signify some important implications for the practical explanations behind the determinants of TFP. It can be advocated based on the estimations that perhaps increasing pesticide use might have improved the fertility conditions that contributed to positive growth for some of the crop productions or it has improved the farming efficiency by significantly altering the intrinsic soil conditions by killing off harmful pests and soil rodents. The negative coefficients for both chemical input use and fertilizer consumption index convey that increasing the use of more chemicals and mechanized inorganic fertilizer use have generated negative impact on TFP either through deterioration of soil fertility or crop destructions attributable to detriments of chemicals and fertilizers. Energy input use has a positive but comparatively feeble impact on TFP. The coefficients of the variables that comprises of the intermediate inputs show mixed and varying outcomes on TFP that is for the most part inconsistent with the findings by White and Hopp (2012) except for pesticide consumption index which has both positively and significantly contributed to TFP. Based on this, it can be stated that to some extent intermediate inputs such as application of modern mechanized pesticide use has certainly improved farming efficiency or has accelerated output productivity by reducing the harmful effects of weeds, diseases and insect pests that would have reduced harvestable produce. The positive but weak impact of energy input on TFP can possibly contend that use of rural energy and direct energy use in production process has positively affected different stages of production such as harvesting, tilling, irrigation use, processing etc that involves use of external inputs and different forms of energy. In this regard, it can be reasonably surmised that use of non-renewable energy inputs such as wind pumps, solar dryer, water wheels and other modern technological deployments in different stages of production have contributed positively to TFP growth but to a much weaker extent compared to pesticide use. Nonetheless, it must be mentioned that several other intermediate inputs cannot be included in the study due to data scarcity and time constraint. The positive however statistically non-significant impact of agricultural R & D implies that indeed research findings have been effectively

implemented towards their practical objectives but to a comparatively lesser magnitude. This outcome reinforces the justification by Alston, Anderson, James and Pardey (2011) that state to state spillover effects of public agricultural research are important to observe as much of the economic impacts of research funding are not ostensible and cannot be captured empirically. Significant impact of overall public sector spending on highways indicate that improvements in agricultural input supply chain have intensified output growth indirectly through efficient transportation system facilitating better supply chain logistics. Better physical access to input markets and other similar conveniences might be relevant to consider.

5. TFP and Output growth

As a continuation of the present study on TFP, the paper has focused on the subsequent impact of TFP index on overall output index for the same period of study. As mentioned earlier, time series regression has been conducted on translog production function, reflected by Model 2 using the fixed effect approach to estimate the impact of TFP on output in general. Again to correct for multicolinearity and unit root non stationarity the first year difference has been taken for all the variables and the regression has been conducted from 1970 to 2004. Again, the z test under the Johansen test for cointegration confirms that variables are covariance stationary. Table 3 presents the regression results for Model 2, which reflects that TFP has a remarkably high impact on output estimation which is both statistically significant at 1% and have an influentially high coefficient estimates. Labor input has a highly negative impact on output estimation having a significance level at 5% reinforcing the USDA ERS findings confirming declining growth rate of labor input over the last 50-60 years. This trend has been applicable for both hired labor and unpaid family labor and self-employed labor combined (Wang, 2014). The negative effect of labor input on output can be explained by the fact that perhaps rapid proliferation of mechanized farming techniques has led to higher substitutability between labor and other mechanized capital and intermediate and energy inputs resulting in lower labor productivity as much of the farm level labor productivity is

dependent on other inputs. As a result considering labor productivity in isolation will expectedly exhibit a notably negative impact on output index. The coefficients of capital input are positive but statistically non-significant signifying that although positive but the overall impact of capital inputs on output is not as influential as that of TFP.

Combining the results of Model 1 and Model 2, it is quiet tenably clear that for the period of study under consideration, TFP has a high impact on output growth. TFP index is mathematically represented by the ratio of output index and the input index and similarly TFPG index is constructed by using the ratio between overall output index and the input index according to the Divisia Method or Social Accounting Approach. Therefore, TFP essentially addresses the residual measure of the output productivity or the variation explaining output growth that is not evidently attributed to traditional input growth such as land, labor and capital. Therefore, based on this study it can be argued that this residual measure can be explained by factors such as mechanized use of pesticides, fertilizers, energy inputs, infrastructural spending, agricultural R & D spending, extension services by government agencies and public and private universities and so forth, which comprehensively constitute TFP. Now considering the results from Model 1, the significant impacts of pesticide use, overall federal spending on highway construction and maintenance and to some extent energy inputs have a collective impact on output. However, if analyzed individually these impacts are not identical as seen from the results of Model 1. A much wider interpretation of the combined results might arguable signify that a rampant mechanization of the overall agricultural sector has certainly accelerated farm level output productivity through better and efficient use of intermediate inputs such as high variety seeds and productive consequences of pesticide use, better rural infrastructure through effective highway systems and better transportation access in rural areas and through increasing advancement of energy inputs in different production stages. Although the negative impacts of fertilizers and chemical use on TFP might contradict the effectiveness of intermediate inputs as a whole in enhancing output or factor productivity. Furthermore, percentage of adult population who are educated (indicated by adult population 25 years or over who have completed high school or college) has a much lower impact with a much lower statistical significance on TFP and consequently on output based on Models 1 and 2. One interpretation of such

weak correlation can be the fact that perhaps any variable related more directly to rural education level rather than national educational data representing adult education might have been more relevant in explaining the relationship between TFP and educational attainment. Now again due to absence of any data that pertains appropriately to rural education or average educational credibility of the farmers both at individual and household level, national data had to be used as a proxy. More generally, educational attainment of the rural adult population is traditionally expected to have a considerable impact on TFP and output growth.

The growth pattern of agricultural TFP and the trend for agricultural farm level output price have been shown in Figure 1 to historically represent the overall contribution of TFP to the output growth level reflected by the changes in output prices. The figure presents a fundamental comparison between the changes in these two variables over time and registers the effect of TFP on output growth. The price index has been deflated based on 1980 prices.

6. Conclusion and Future Implications

This paper presents an empirical estimation of TFP and overall farm level output and the main objective is to identify the major sources of TFP and to what extent those factors contribute to output reflected by the impact of TFP on output level. Any modification or further extension of the methodology generates scope of future research on the topic which again unleashes the possibilities for further intriguing perspectives. This particular study looks uses the national data level for all the variables. The application of the same methodology on state level data enables us to disintegrate the impact of each of the variable at a state level and therefore compare the state level differences in factor productivity and its contribution to output level. It would be interesting to observe how each of the impact of explanatory variables in TFP equation or Model 1 varies according to state and what the most important sources of TFP are based on individual states. Such a comparative estimation is essential for policy consideration pertaining to productivity growth and long term food safety issues. The national outcomes presented in this study certainly give an overall idea on the major sources of productivity growth in US

agricultural for a certain period of time that can sufficiently explain the major determinants for input productivity and output growth pattern and forecast future trends in productivity patterns. But the scope of this study is not only limited to observe and predict the direction for future productivity trends but to devise long term policies that can effectively combat food shortage, rural poverty and long term agricultural sustainability. All of these issues are inseparably affiliated with patterns and major sources of productivity growth that has been highlighted in this paper.

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Appendices

Table1. Sources of agricultural output growth in the U.S. (annual average rate in %)

	1948-2009	1948-1953	1953-1957	1957-1960	1960-1966	1966-1969	1969-1973	1973-1979	1979-1981	1981-1990	1990-2000	2000-2007	2007-2009
Output Growth	**1.63**	**1.18**	**0.96**	**4.03**	**1.21**	**2.24**	**2.65**	**2.26**	**1.54**	**0.96**	**1.84**	**0.77**	**1.88**
Sources of growth													
Input growth	**0.11**	**1.34**	**0.28**	**0.50**	**0.05**	**-0.08**	**0.46**	**1.64**	**-1.85**	**-1.22**	**0.31**	**0.14**	**-1.80**
Labor	**-0.52**	**-0.81**	**-1.08**	**-0.83**	**-0.81**	**-0.61**	**-0.38**	**-0.19**	**-0.22**	**-1.43**	**-0.34**	**-0.35**	**-0.64**
Capital	**0.02**	**0.54**	**0.15**	**0.03**	**0.08**	**0.32**	**0.14**	**0.32**	**0.23**	**-0.61**	**-0.21**	**0.05**	**0.35**
Land	**-0.08**	**0.02**	**-0.17**	**-0.16**	**-0.07**	**-0.22**	**-0.29**	**0.00**	**-0.12**	**-0.09**	**0.00**	**-0.08**	**-0.12**
Intermediate goods	**0.69**	**1.58**	**1.38**	**1.45**	**0.85**	**0.43**	**0.99**	**1.50**	**-1.74**	**-0.09**	**0.87**	**0.52**	**-1.39**
Total factor productivity	**1.52**	**-0.16**	**0.68**	**3.53**	**1.16**	**2.32**	**2.19**	**0.62**	**3.39**	**2.19**	**1.53**	**0.63**	**3.68**

Note: The sub periods are measured from cyclical peak to peak in aggregate economic activity

Data Source: Economic Research Service

Table2. Regression estimates for Model 1

Variable	Regression Coefficient	Standard error	't' Statistics	Level of significance
Total agricultural RD	.1158807	.1891557	0.61	0.546
Index of Fertilizer Con	-02431873	.1106068	-2.20	0.037
Index of Pesticide Con	.3724586	.0960855	3.88	0.001
Energy use Index	.0175786	.008165	2.15	0.041
Chemical use Index	-.3054241	.0934931	-3.27	0.003
Education	-1.16399	.9208955	-1.26	0.218
Total Federal Highway Finance	.3524681	.2074958	1.70	0.102
Machinery Tractor per 100sq.km of arable land	.4904896	.1321612	1.13	0.267
Cons	.0040761	.0161674	0.25	0.803
Adjusted R square	0.3335			

Table3.Regression estimates for Model 2

Variable	Regression Coefficient	Standard error	't' Statistics	Level of significance
Annual Capital Index	.1605961	.2085899	0.77	0.447
Annual labor Index	-.4596708	.2512235	-1.83	0.077
Annual TFP Index	.971049	.1299351	7.47	0.000
Cons	.00757	.0062054	1.22	0.232
Adjusted R square	0.6967			
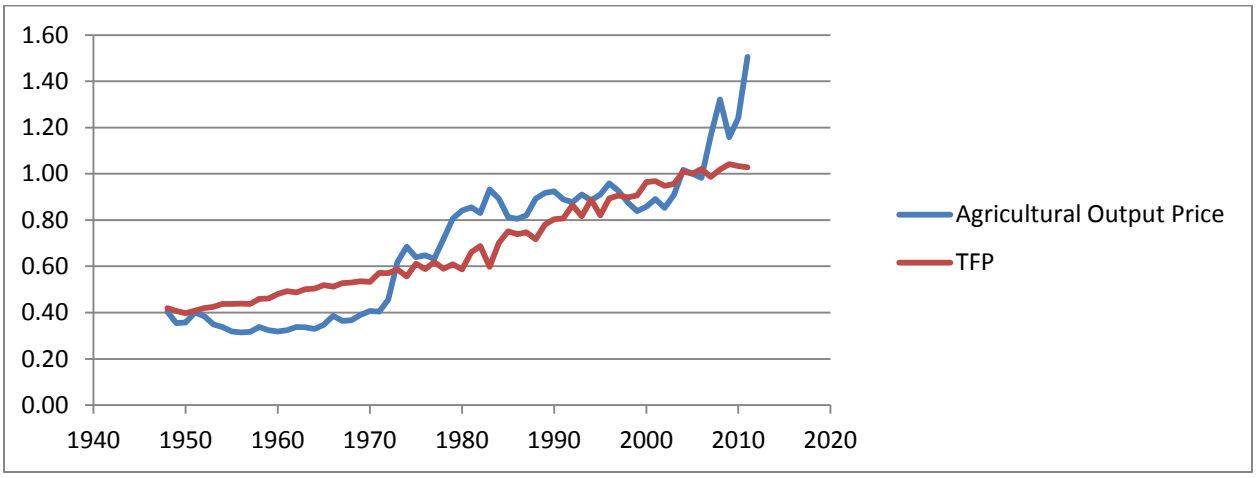
Figure 1.Agriculture Output Price and Agricultural TFP