

Causality between TFP, R&D and Prices: Unconditional and Conditional Linear Feedback¹

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Abstract

This paper estimates the unconditional and conditional linear dependence between exogenous supply (R&D), endogenous demand (prices) and TFP based on the linear feedback method. Unit root tests are performed for Nebraska agriculture sector data spread over 1936-94 time period. Results indicate the influence of both R&D and prices on productivity.

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This paper uses Nebraska agriculture sector data to investigate conditional and unconditional linear dependence³ of the supply [exogenous research and development (R&D) expenditures- push] and the demand [endogenous price changes driven by innovation- pull] changes on Total factor productivity⁴ (TFP). Productivity growth rate measures the increase in output vector given an input vector or the decrease in the input vector to produce the output vector. This is equivalent to a shift in the production function or input requirement set under constant returns to scale with producers characterized by competitive behavior and zero profits. TFP, the major source of economic growth and welfare improvement, has been traditionally identified with supply driven changes especially R&D investments and insignificant demand driven changes along the supply curve.

Strong arguments have been made for the exogenous supply changes [Baumol and Wolff, 1983; Pardey and Craig, 1989; Huffman and Evenson, 1993 for research and development expenditures] as the principal causal factor of TFP. The traditional unidirectional causality analysis involving a meta-production function or the regression of productivity on research expenditures fortifies the supply side impacts. Even though there is no clear empirical

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³ The measure of linear dependence is the sum of the measure of causality from the first series to the second, causality from the second to the first, and contemporaneous linear feedback.

⁴ Productivity and Total factor productivity represent the same meaning.

relationship between the output prices and productivity, induced innovation theory [Schmookler 1966; Scherer, 1982; Jaffe Adam, 1988 and Dosi, 1988 -innovation literature] suggest conditional causality on productivity. Alternatively, productivity might be the causal factor indirectly influencing R&D investments and the price changes through resource use mix, quantity and quality of output production. This unconditional linear dependence would help us to test the existing notion of weak (strong) influence of the demand price (supply R&D expenditures) changes on productivity.

This paper estimates the unconditional and conditional linear dependence between the exogenous supply (R&D), endogenous demand (prices) and TFP based on the linear feedback method. Unit root tests are performed and further cointegration test would also be conducted provided the variables are integrated of the same degree. The Nebraska agriculture sector TFP, R&D stock and the price data is spread over 1936-94 time period. The second section presents the linear feedback and unit roots models. Data description is detailed in the third section followed by empirical application, results and conclusion in the fourth and last section respectively.

R&D Expenditures, Prices and Productivity



Agricultural research system [ARS] is starting to face new challenges from the private research

investments due to strengthened intellectual property rights in the post World War II scenario. It has long been recognized that the research investment accompanied by the new knowledge generated makes a vital contribution to the economic development and productivity. Research conducted at state experimental stations, land grant universities and USDA benefits not only farmers (lower costs and higher profits) but also the consumers (lower food prices). Doubts have been raised of under-investments in public research [Fox, 1985], but on the contrary empirical higher rates of returns to research [Griliches, 1964,1992; and Huffman and Evenson, 1993] has lead to higher private R&D investment compared to public R&D.

The nature and magnitude of the causality between research expenditures and productivity has been examined but do prices affect productivity simultaneously? There has been empirical studies indicating negligible influence of the demand shifts on technical change at the firm and the aggregate level. This might be due to the way the price data is constructed and used in the analysis. However in the time series framework, the linear causality between R&D, prices and productivity supported by economic theory can be tested. As indicated prices of outputs could be influenced by productivity conditional on the R&D expenditures apart from the influence of R&D on productivity with conditional price changes. This has been theoretical addressed by Baumol and Wolff. According to them, *productivity effects the quantity of resources available for investment generally and for investment in R&D in particular. It also influences the price of output and, hence, the cost of R&D relative to output price. In both these ways investment in R&D is apt to be affected.* Three alternative causal relationship to be tested based on economic theory are modeled in a static framework

1. Unconditional linear dependence between productivity and R&D expenditures and prices.
2. Linear causality between productivity and prices conditional on R&D expenditures.
3. Linear causality between R&D expenditures and productivity conditional on prices.

Linear Feedback and Unit Root Econometric Models

Testing for Unit roots:

The augmented Dickey Fuller (ADF) and Phillips-Perron (PP) unit root tests are performed to test the stationarity of the variables used in the analysis. Further cointegration test will be performed if the variables are integrated of the same degree. The time series property of unit roots was tested for TFP quantity index, research and development stock and output price index prior to estimating the model since it has implication for economic theory and modeling. The ADF test statistic is based on two forms of OLS regression estimation results from suitably specified regression equations:

$$(1a) \quad D Y_t = a_0 + a_1 Y_{t-1} + \sum_{j=1}^P g_j D Y_{t-j} + e_t$$

$$(1b) \quad D Y_t = a_0 + a_1 Y_{t-1} + a_t t + \sum_{j=1}^P g_j D Y_{t-j} + e_t$$

where (1a) is with constant, no-trend and (1b) is with constant, trend. P is the number of lagged terms to ensure the errors are uncorrelated. The null hypothesis to be tested is $\alpha_1 = 0$. PP (1988) developed a generalization to the DF procedure, which is nonparametric with respect to nuisance parameters allowing for a wide class of weakly dependent and possibly heterogeneously distributed data. The PP test is based on OLS regressions:

$$(2a) \quad Y_t = a_0 + a_1 Y_{t-1} + e_t$$

$$(2b) \quad Y_t = a_0 + a_1 Y_{t-1} + a_t t + e_t$$

with (2a) and (2b) definition similar to equation (1). The null hypothesis to be tested is $\alpha_1 = 1$.

The ADF and PP test take the presence of a unit root (a stochastic trend) in the time series as the null hypothesis.

Unconditional and Conditional Linear Feedback

Following the linear feedback concept of Geweke (1982, 1984) and McGarvey (1985), the unconditional and conditional measures are developed here. The degree of linear dependence between productivity and output price (R&D stock) from the demand side (supply side) is estimated. This would provide us with measure of both the unconditional linear dependence as well as the conditional linear causality between productivity and R&D, prices.

Let a nondeterministic multiple time series w_t be partitioned into subvectors y_t , x_t and z_t representing R&D stock in constant 1992 dollars, total factor productivity and output price index respectively. The measures of linear dependence in terms of y_t (a scalar process) and z_t conditional on x_t and each linearly indeterministic stationary process are based on the following projection equations:

$$\begin{aligned}
 (3a) \quad y_t &= \sum_{s=1}^{\infty} a_{1,s} y_{t-s} + \sum_{s=1}^{\infty} b_{2,s} z_{t-s} + \sum_{s=1}^{\infty} g_{3,s} x_{t-s} + e_{1,t} \\
 (3b) \quad y_t &= \sum_{s=1}^{\infty} a_{1,s} y_{t-s} + \sum_{s=0}^{\infty} b_{2,s} z_{t-s} + \sum_{s=1}^{\infty} g_{3,s} x_{t-s} + e_{2,t} \\
 (3c) \quad y_t &= \sum_{s=1}^{\infty} a_{1,s} y_{t-s} + \sum_{s=1}^{\infty} g_{3,s} x_{t-s} + e_{3,t}
 \end{aligned}$$

where $\text{var}(\epsilon_{1,t})$, $\text{var}(\epsilon_{2,t})$ and $\text{var}(\epsilon_{3,t})$ are the variances of the respective equations with y_t , x_t and z_t representing TFP, R&D and output price index (OPI).

The sub vectors reflect an interest in two sets of conditional feedback measures, one between y and z conditional on x , to test if demand side price changes affect TFP given R&D stock. The other is the feedback measures between x and y conditional on z to test if there is reversal causality from R&D to TFP given output prices. Geweke defines the linear dependence between y and z conditional on x as:

$$(4) \quad F_{z,y|x} = F_{z \rightarrow y|x} + F_{y \rightarrow z|x} + F_{z,y|x}$$

Using Geweke's notation, overall feedback from z to y conditional on x is defined as:

$$(5) \quad F_{z \rightarrow y|x} = \log(\text{Var}(e_3) / \text{Var}(e_1))$$

The measure of instantaneous or contemporaneous feedback between y and z conditional on x is defined as:

$$(6) \quad F_{z,y|x} = \log(\text{Var}(e_1) / \text{Var}(e_2))$$

The feedback from y to z conditional on x is found by switching z and y in equations 3a and 3c and in the definition of directional feedback. If x is zero in equations (3a, 3b, 3c), the above measures become the unconditional feedback measures and denoted as $F_{z \rightarrow y}$, $F_{y \rightarrow z}$ and $F_{z,y}$.

Nebraska TFP, Output Price Index and R&D Stock

Nebraska agriculture sector TFP, output price index and R&D stock is used in this linear feedback analysis spread over the time period, 1936-94. Nebraska agriculture sector TFP has been calculated accounting for the quantity and quality changes of outputs and inputs, the details of which are presented in Shaik (1998).

An aggregate Theil-Tornquist output price index [OPI] is formed by share weighted percentage changes in livestock commodities, field crops and oils and vegetable crops. The time series index is computed by choosing a particular year as 100 and cumulating the measure of rate of change in prices.

R&D expenditures are investments in human capital. Investments in research today

would have lagged and dynamic consequences that last for future periods. The lag is due to the time gap between the expenditures made on research and the increment in knowledge/new technology that effects production and productivity. Since productivity depends on the flow of knowledge generated by stock of R&D, three different research lag structures were constructed. The various research structures using a 35 year lag period are: *Inverted-V* [here we assume that knowledge accumulates for the first 16.5 years and then knowledge tends to decline for the next 16.5 years]; *Trapezoidal* [in this structure there is no knowledge generated in the first 3 years, but increasing knowledge is felt for the next 5 years. Knowledge is maintained for the next 6 years and the rest of 21 years knowledge declines]; and the last is that used in the UC Davis study [In the first 7 years knowledge is generated followed by maintaining the same knowledge for the next 8 years and decline in accumulation of knowledge for the rest 20 years]. The data for annual research expenditures is collected from the USDA, CRIS. The University of Nebraska-Lincoln in its annual ARD report publishes the R&D expenditure data. Implicit GDP price deflator was used instead of R&D price deflator to obtain R&D stock in real dollars.

Empirical Application and Results

The average annual growth rates of the traditional Theil-Tornquist total factor productivity (TFP) index, output price index and R&D stock (in constant 92 Mil dollars) for various time periods are presented in Table 1. Figure 1 illustrates the time series data for Nebraska agriculture sector TFP, output price index and research stock. Negative annual growth rate was indicated by TFP during the 1971-80 time period, R&D stock prior to 1950 and for output prices during 1951-60 and 1981-94 time period.

Table 1. Average Annual Rates of Growth

<i>Year</i>	<i>TFP</i> <i>(1936=100)</i>	<i>R&D</i> <i>(1992=100)</i>	<i>Output Price Index</i> <i>(1936=100)</i>
1936-50	1.713	-0.570	5.066
1951-60	2.210	6.501	-3.159
1961-70	1.304	7.375	1.566
1971-80	-1.011	2.722	9.267
1981-94	2.292	4.225	-0.228
1936-94	1.484	3.842	2.562
1936-80	0.863	3.727	3.672

The highest annual productivity growth rate of 2.292 and negative growth rate in prices occurred during 1980-94. In the 1970s we had seen negative productivity growth rate and highest price growth rate. The results of unit roots analysis are presented in Table 2.

Table 2. Unit Root test for TFP, R&D stock and Prices

<i>Variables</i>	<i>Trend</i>	<i>Dick Fuller</i> <i>Test</i>	<i>Phillip Perron</i> <i>Test</i>
TFP	T	-2.8094 (-5.0484)	-2.6301
R&D Stock	T	-0.7587 (-4.1156)	-0.0305
Price Index	T	-1.9141 (-4.9152)	-2.4351
Critical values (critical level)		-3.13 (0.05)	

Values in the bracket indicate the calculated value for the first differenced data of TFP index and second differenced data for R&D and prices

The results indicate that all the variables [TFP index, R&D stock and output price index] are nonstationary since we cannot reject the unit root. Given that these variables have unit roots, the first differenced data was again tested for unit roots. It was found that the first differenced TFP

data was stationary with no unit roots. In the case of the other two first differenced variables, the ADF and PP test failed to reject the null hypothesis of unit roots. After the second difference was taken we could reject the null hypothesis of unit roots for the two variables. Given that the variables are not integrated of the same degree, it was not possible to conduct the cointegration test. However it is feasible to estimate the cointegration test with first differenced TFP data and second differenced R&D and price data but not attempted because the implications are unclear.

The first differenced data of TFP index, the second differenced data of research expenditures and the output price index was used in the estimation of linear feedback measures. Table 3 presents the unconditional linear dependence estimates for the bivariate system of TFP and the R&D supply changes; TFP and the demand output price changes under alternative 1, 3, 6, 9 lag structures. The values in the parenthesis are the percentages of the absolute value of the linear feedback measures. Results of the unconditional feedback estimates show that TFP and R&D stock are not linearly independent. About more than half of the total linear dependence between the two series is explained by contemporaneous feedback for one and three lagged structure regressions. The magnitude of feedback from TFP to R&D (on an average explains 50% of the causality) is always greater than that from R&D to TFP (on an average explains 20% of the causality) for all the lag structures except for the single case.

The unconditional linear dependence estimates between TFP and demand price under alternative 1, 3, 6, 9 lag structures shows the contemporaneous feedback on an average explains one-third of the variation. The feedback measures from TFP to prices explain 45 percent of the causality compared to less than 1/5th causality from prices to TFP.

The conditional linear dependence estimates for the bivariate system of 1)TFP and price changes given R&D changes (supply) and 2) R&D changes and TFP given output price changes

(demand) under alternative 1, 3, 6, 9 lag structures are presented in Table 4. The linear feedback between productivity and prices conditional on R&D expenditures corresponding to the unconditional linear feedback measure explains a greater percentage of the causality under single lag compared to three lagged regression. The results show the influence of the supply and the demand changes on TFP with greater influence of supply. However for the 6 and 9 lagged regressions, changes in TFP is explained by the demand price changes and diminishing R&D influence. The linear dependence estimates between R&D stock and TFP conditional on the price changes show that they are linearly dependent. For the first two lag cases the changes in the R&D is better explained by TFP changes, however for 6 and 9 lagged regressions the changes in R&D is explained by TFP and demand price changes.

Overall the unconditional and condition linear dependence measures show that TFP is affected by the exogenous R&D supply changes and the endogenous demand price changes.

Conclusions

The previous empirical evidence of negligible affect of demand side forces on the productivity growth rate has been suggested otherwise by the unconditional and conditional linear feedback measures using Nebraska agriculture sector data. The contemporaneous feedbacks along with supply and demand feedback measures explain changes in TFP. Further research needs to be conducted on the implications of conducting a cointegration test with dissimilar degrees of integrated variables as well as the consequence of using unit root corrected data on the results. Confidence interval based on Monte Carlo simulations helps to fortify the results.

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Table 3. Unconditional Linear Dependence measures with Alternative Lag Structure

	<i>Linear Dependence between TFP and R&D</i>			
	$F_{x \rightarrow y}$	$F_{y \rightarrow x}$	$F_{x, y}$	$F_{x, y}$
Lag 1	4.7403 (0.465)	0	5.4625 (0.535)	
Lag 3	2.5690 (0.120)	4.4084 (0.207)	14.3706 (0.673)	21.3481
Lag 6	-9.87 (0.220)	-32.3191 (0.720)	2.6971 (0.060)	-39.4967
Lag 9	4.7607 (0.261)	10.4379 (0.573)	-3.0173 (0.166)	12.1813
	<i>Linear Dependence between TFP and Prices</i>			
	$F_{z \rightarrow y}$	$F_{y \rightarrow z}$	$F_{z, y}$	$F_{x, y}$
Lag 1	4.7089 (0.508)	0	4.566 (0.492)	
Lag 3	9.9322 (0.314)	11.0425 (0.349)	10.6298 (0.336)	31.6046
Lag 6	3.4637 (0.064)	-28.5337 (0.527)	-22.1790 (0.409)	-47.2490
Lag 9	-12.2052 (0.200)	-28.6371 (0.469)	20.2758 (0.332)	-20.5673

Table 4. Conditional Linear Dependence measures with Alternative Lag Structure

	<i>Linear Dependence between TFP and Prices conditional on R&D</i>			
	$F_{z \rightarrow y x}$	$F_{y \rightarrow z x}$	$F_{z, y x}$	$F_{x, y z}$
Lag 1	-1.71307 (0.172)	-2.7820 (0.279)	5.4813 (0.549)	0.9862
Lag 3	9.0299 (0.213)	-27.0367 (0.636)	-6.4112 (0.151)	-24.418
Lag 6	-4.6662 (0.176)	9.2143 (0.347)	-12.6702 (0.477)	-8.1221
Lag 9	24.7966 (0.686)	-1.06113 (0.029)	10.3114 (0.285)	34.0469
	<i>Linear Dependence between R&D and TFP conditional on Prices</i>			
	$F_{x \rightarrow y z}$	$F_{y \rightarrow x z}$	$F_{x, y z}$	$F_{x, y z}$
Lag 1	-22.1751 (0.685)	-5.2385 (0.162)	-4.9358 (0.153)	-32.3494
Lag 3	17.5007 (0.420)	13.1943 (0.317)	-10.9589 (0.263)	19.7360
Lag 6	-3.6261 (0.134)	10.3784 (0.383)	13.1099 (0.484)	19.8621
Lag 9	1.7637 (0.046)	8.3521 (0.218)	-28.213 (0.736)	-18.0974

Figure 1. Nebraska TFP, R&D and Prices

