Süleyman Demirel Üniversitesi
İktisadi ve İdari Bilimler
Fakültesi Dergisi
Y.2011, C.16, S.1 s.79-92.

Suleyman Demirel University
The Journal of Faculty of Economics
and Administrative Sciences
Y.2011, Vol.16, No.1 pp.79-92.

CAUSALITY RELATIONSHIP BETWEEN TOTAL R&D INVESTMENT AND ECONOMIC GROWTH: EVIDENCE FROM UNITED STATES

TOPLAM AR&GE YATIRIMLARI İLE EKONOMİK BÜYÜME ARASINDA NEDENSELLİK İLİŞKİSİ: AMERİKA BİRLEŞİK DEVLETLERİNDEN KANIT

Doç.Dr.Selçuk AKÇAY*

ABSTRACT

This paper tests the cointegration and causal relationship between economic growth and total R&D investment for the United States for the period 1960-2007 using Johansen and Juselius (1990) cointegration test and the Granger no-causality approach developed by Toda and Yamamoto (1995), in a five variable vector autoregression (VAR) model. Johansen and Juselius cointegration test reveals one cointegrating vector among the variables. The results of Toda and Yamamoto approach indicate two-way causality between total R&D investment and economic growth.

ÖZET

Bu çalışma, beş değişkenli vektör otoregressif (VAR) modeli kullanarak, 1960-2007 döneminde Amerika Birleşik Devletlerinde toplam araştırma ve geliştirme yatırımları ile ekonomik büyüme arasındaki eşbütünleşme ve nedensellik ilişkisini incelemektedir. Eşbütünleşme için Johansen - Juselius (1990), nedensellik için Toda ve Yamamoto (1995) yaklaşımları kullanılmıştır. Eşbütünleşme testi sonuçlarına göre değişkenler arasında uzun dönemli bir ilişki vardır. Toda ve Yamamoto nedensellik testi sonuçlarına göre toplam AR&GE ile ekonomik büyüme arasında iki yönlü nedensellik ilişkisi bulunmuştur.

R&D Investment, Growth, Cointegration, Toda – Yamamoto Causality Test
AR&GE Yatırımları, Büyüme, Eşbütünleşme, Toda –Yamamoto Nedensellik Testi

* Afyon Kocatepe University, Faculty of Economics and Administrative Sciences, Department of Economics, Afyonkarahisar, Turkey.

1. INTRODUCTION

Research and Development (R&D), defined as "creative work undertaken on a systematic basis in order to increase the stock of knowledge and the use of this stock of knowledge to devise new applications" (OECD, 1993, p. 29), leads to new technological breakthroughs, thereby increases productivity, economic growth and prosperity. According to Grossman and Helpman (1994), technology, which is the result of R&D activities and investment, has been "the real force behind perpetually rising standards of living" (p. 24).

The relationship between R&D investment and growth has attracted a great deal of attention amongst policy makers and economist. The literature on R&D-growth linkage has been influenced by two recent developments. First, the endogenous growth theory has highlighted the importance of R&D in the economic growth. Second, new econometric methods, such as cointegration and causality tests (Toda-Yamamoto, 1995), have further extended the debate on R&D-growth nexus.

Theoretical and empirical studies (cross-sectional, time series and panel data) have indicated that investment in R&D is vital for economic growth. Theoretical, models developed by Romer (1990), Grossman and Helpman (1991a, 1991b, 1991c) and Aghion and Howitt (1992) demonstrate that an increase in the level of resources devoted to R&D will increase economic growth (scale effect).

Empirical studies, such as Griliches (1980), Mansfield (1988), Cohen and Levinthal (1989), Feller (1990), Lichtenberg (1992), Griliches (1992), Griliches (1994), Jovanovic and Nyarko (1995), Adams and Griliches (1996), Madden *et al.* (2001), Fraumeni and Okubo (2002), Griffith *et al.*, (2004), Aiginer and Falk (2005), Mayhew and Neely (2006), Griffith *et al.*, (2006), Benum (2007), Maloney and Rodriguez-Clare (2007), Ulku (2007), Falk (2007), have emphasized the importance of R&D investment for technological progress, productivity, and economic growth.

While R&D activities and investment promote GDP growth, it is also possible that GDP growth can induce stronger incentives for R&D investment. Braconier (2000), using pooled time-series data from 10 OECD countries for the period of 1973-1992, found that expected per capita income is one of the important determinants of R&D expenditures. Wang (2010) examined determinants of R&D investment, using the Extreme-Bounds-Analysis approach for 26 OECD countries. The results indicate that income growth rate is a fragile determinant of R&D investment.

Sylwester (2001) investigated relationship between R&D and economic growth in 20 OECD and G7 countries, employing multivariate regression analysis. While no strong association is found between R&D expenditures and economic growth in OECD countries, a positive relationship between industry R&D expenditures and economic growth is detected in the case of the G7 countries.

Pessoa (2010) showed that country specific factors are important in modeling the R&D - growth nexus. Therefore, the structure of the relationship between R&D and economic growth is not same for all countries and innovation policy that relies only on increasing R&D expenditures is not effective for economic growth (p.6).

What is the causal relationship between economic growth and R&D investment? According to endogenous growth theory, higher level R&D investment leads to higher level of total factor productivity (TFP), which in turn induces economic growth. It is also possible that economic growth, may positively affect total R&D investment. Thus, it can be argued that total R&D investment can Granger – cause economic growth, just as economic growth can Granger – cause total R&D investment.

The purpose of this study is to investigate Granger-causality between economic growth and real total R&D (TRD) investment in the US. The US chosen as a case study for two reasons: First, in terms of total R&D investment US is one of the top countries in the world. According to OECD's Science Technology and Industry Scoreboard (2009), the US accounted for almost 40% of the R&D expenditures in the OECD between 1997 and 2007. This country's total R&D expenditure was 368,8 billions PPP$, and its R&D intensity (2.7% of GDP) remained well above the G7 average (2.2%) in 2007. Second, since R&D investment play crucial role in US economy, studies related to growth-R&D nexus on the US economy are yet to be completed.

This study differs from the previous studies about US in two ways. First, it uses a new dataset covering the period of 1960-2007. Second, contrary to the previous studies that employed either standard Granger causality test or Granger causality test based on the Error Correction Model (ECM), it employs Granger no-causality approach developed by Toda and Yamamoto (1995). With the above in mind, the rest of the study is organized as follows. Section II provides literature review. Section III describes data and the empirical methodology. Section IV presents empirical results. Conclusions and policy implications are presented in section V.

2. LITERATURE REVIEW

The link between R&D and economic growth is empirically examined on firm, industry and national levels for the US.

Fraumeni and Okubo (2002), using the National Income and Product Account framework of the U.S. over the period of 1961–2000, estimated that the returns to R&D capital accounted for 10% of growth in real GDP. Moreover, they found that R&D investment increased savings rate by 2%.

Goel, Payne and Ram (2008) examined the long-run R&D-growth relationship at a disaggregated level by considering the roles of federal, non-federal, and defense R&D outlays for the US. In doing so, they employed new bounds-testing and ARDL (autoregressive distributed lag) procedures developed by Pesaran, Shin and Smith (2001), using annual data for the period of 1953 - 2000. The results indicated that economic growth was more strongly associated with federal R&D than with non-federal R&D. It was also found that economic growth was more strongly associated with defense R&D than with non-defense (federal) R&D.

A study report prepared by European Commission (2008) examined causality link between gross R&D expenditures (GERD) and real GDP for nine European Union countries and the US for the period of 1981-2006. In the case of US, one-way causality running from real GDP to GERD was detected.

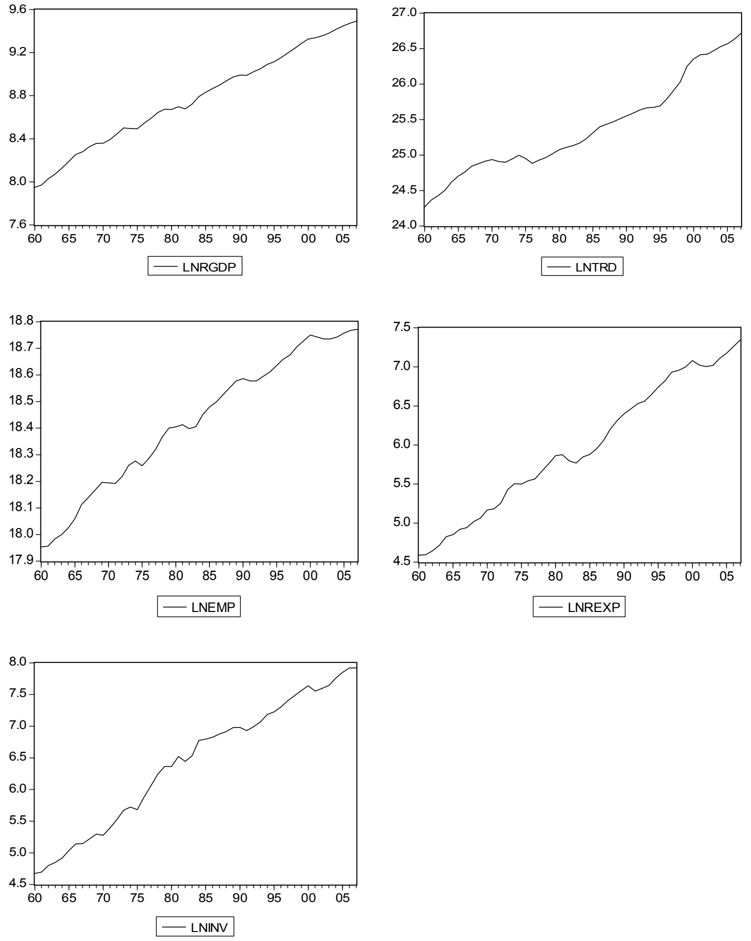
Developing highly stylized theoretical endogenous growth model and using a structural vector autoregressive (SVAR) model, Estrada and Montero (2009) studied the impact of R&D investment on the long-run growth for Japan, Germany, UK, France, Italy, Spain and US for the period of 1970-2006. Their results indicated that both private and public R&D investment induced long term growth in the US.

3. DATA AND EMPIRICAL METHODOLOGY

3.1. The Data and Model

This study uses annual real GDP, real total R&D investment, employment, real gross domestic investment (public + private) and real export revenues time series data covering the 1960-2007 periods for US. All the data are taken from the U.S. Department of Commerce, Bureau of Economic Analysis web site and are transformed into natural logarithm scale prior to analysis. Figure 1 shows the logarithmic plots of the time series. This figure illustrates that real GDP, real gross domestic investment, total R&D investment, and employment and export exhibit upward trends, indicating that these variables may move together.

Fig. 1: Logs of Real GDP, Total R&D Investment, Real Exports, Employment and Real Gross Domestic Investment in US.



Using the variables proposed by endogenous growth theory, the following production function is estimated.

$$Y_t = f\,(INV_t, TRD_t, EMP_t, EXP_t) \qquad (1)$$

where Y_t is the real GDP; INV_t , TRD_t , EMP_t , EXP_t are gross domestic investment (public+private), total R&D investment, total full–time and part time employees by industry and real revenues of exports respectively. Incorporating export into production function is not a new idea. Previous empirical studies such as Balassa (1978), Tyler (1981), Ram (1985), Fosu (1990), Sheehey (1992), Burney (1996), Shan and Sun (1999) included exports in the aggregate production function.

3.2. The Granger Causality Procedure

One of the advantages of Vector Autoregression (VAR) model is that it enables us to detect the direction of causality. Toda and Yamamoto (1995) no-causality test is employed to find out the direction of causality between real GDP and TRD.

Toda and Yamamoto method is chosen due to (as noted by Shirazi and Abdul Manap, 2005, p. 478) following reasons: "a) the standard Granger (1969) causality test for inferring leads and lags among integrated variables is likely to give spurious regression results and F-test becomes invalid unless the variables are cointegrated, b) the error correction model (Engle and Granger 1987) and the VAR error correction model (Johansen and Juselius 1990) as alternatives for testing of non causality between time series are cumbersome, c) Toda and Phillips (1993) claimed that the Granger causality tests in Error Correction Model (ECM) still contain the possibility of incorrect inference and suffer from nuisance parameter dependency asymptotically in some cases."

Toda and Yamamoto (1995) test does not require knowledge of the integration and cointegration properties of the system. It can be applied even when there is no integration or stability, and when rank conditions are not satisfied 'so long as the order of integration of the process does not exceed the true lag length of the model' (Toda and Yamamoto, 1995, p.225).

Toda and Yamamoto causality test involves estimation of an augmented VAR ($k+d_{max}$) model where k is the optimal lag length in the original VAR system, and d_{max} is the maximal order of integration of the variables in the VAR system. The procedure employs a modified Wald (MWald) test for restrictions on the parameters of a VAR (k), where k is the lag length in the model. The MWald statistic has an asymptotic χ^2 distribution when the augmented VAR ($k+d_{max}$) is estimated.

According to Rambaldi and Doran (1996) MWald tests for testing Granger no-causality increases efficiency when Seemingly Unrelated Regression (SUR) models are employed in the estimation. Toda and Yamamoto Granger no-causality test is employed in this study by estimating the following five-variate VAR model using the SUR method respectively.

$$\begin{bmatrix} \ln GDP_t \\ \ln TRD_t \\ \ln EMP_t \\ \ln EXP_t \\ \ln INV_t \end{bmatrix} = A_0 + A_1 \begin{bmatrix} \ln GDP_{t-1} \\ \ln TRD_{t-1} \\ \ln EMP_{t-1} \\ \ln EXP_{t-1} \\ \ln INV_{t-1} \end{bmatrix} + A_2 \begin{bmatrix} \ln GDP_{t-2} \\ \ln TRD_{t-2} \\ \ln EMP_{t-2} \\ \ln EXP_{t-2} \\ \ln INV_{t-2} \end{bmatrix}$$

$$+ A_3 \begin{bmatrix} \ln GDP_{t-3} \\ \ln TRD_{t-3} \\ \ln EMP_{t-3} \\ \ln EXP_{t-3} \\ \ln INV_{t-3} \end{bmatrix} + \begin{bmatrix} \varepsilon_{GDP} \\ \varepsilon_{TRD} \\ \varepsilon_{EMP} \\ \varepsilon_{EXP} \\ \varepsilon_{INV} \end{bmatrix} \quad (2)$$

Where: $A's$ are four by four matrices of coefficients with A_0 as an identity matrix.

To test the hypothesis that there is "no Granger causality from total R&D investment to GDP", I test, $H_0 = \alpha_1^{(12)} = \alpha_2^{(12)} = 0$, where $\alpha_i^{(12)}$ are coefficients of TRD_{t-1} and TRD_{t-2} respectively in the first equation of system (2) where the system is being estimated as a VAR(3).

The existence of causality from total R&D investment to growth can be established through rejecting the above null hypothesis which requires finding the significance of the MWald statistic for the group of the lagged independent variables identified above. A similar testing procedure can be applied to the alternative hypothesis that "no Granger causality from GDP to total R&D investment", to test $H_0 = \alpha_1^{(21)} = \alpha_2^{(21)} = 0$, where $\alpha_i^{(21)}$ are coefficients of GDP_{t-1} and GDP_{t-2} respectively in the second equation of system (2) where the system is being estimated as a VAR(3).

4. EMPIRICAL RESULTS

4.1. Order of Integration and Cointegration Test

The unit root tests have to be performed to test whether variables involved are stationary or not. For this purpose, an Augmented Dickey – Fuller (ADF) (1981) unit root test is carried out on the time series in levels and differenced forms. Result of unit root test is reported in Table 1. The results show that we can not reject the null hypothesis of unit roots for all variables in level forms. However, the null hypothesis is rejected when the ADF test is applied to the first differences of each variable. The first differences of the lnGDP, lnINV, lnTRD, lnEMP and lnEXP are stationary indicating that these variables are in fact integrated of order one, *I*(1).

Table 1: Unit root test for the variable under study using ADF test

Variables	Level	Critical value	First difference	Critical value	Integration Order I(d)
lnGDP	-2.911 (0)	-4.165	-5.225***(0)	-3.581	1
lnTRD	-1.407 (1)	-4.170	-3.435** (1)	-2.928	1
lnINV	-1.483 (1)	-4.170	-5.226***(1)	-3.584	1
lnEMP	-2.412 (1)	-4.170	-4.849***(1)	-3.584	1
lnEXP	-3.098 (1)	-4.170	-4.390***(1)	-3.584	1

Notes: The numbers in parentheses indicates the selected lag order of the ADF model. Lags are chosen based on Akaike Information Criterion (AIC). *** and ** indicate significance at 1% and 5% levels respectively. EViews 5.0 was used for all computations.

The optimal lag length is important to identify the true dynamics of the model. To determine optimal lag length of VAR system, the sequential modified LR test statistic (LR), Final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SC), and Hannan-Quinn information criterion (HQ) lag selection criteria are used. The result of selecting optimal lag length of VAR is reported in Table 2. LR, FPE, AIC, SC and HQ information criterion indicate that lag order of VAR (k) is 2, for five-variate VAR.

Table 2: Lags under different criteria for five-variate VAR model

Lag	LR	FPE	AIC	SC	HQ
0	NA	7.15e-11	-9.171739	-8.970999	-9.096905
1	561.5163	1.22e-16	-22.45848	-21.25404	-22.00948
2	85.83834*	3.11e-17*	-23.87203*	-21.66389*	-23.04885*
3	29.22843	3.85e-17	-23.76879	-20.55695	-22.57145

Notes:* indicates lag order selected by the criterion; LR: sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

As Engle and Granger (1987) pointed out, only variables with the same order of integration could be tested for cointegration. Since all the series are integrated with the same order I(1), Johansen and Juselius (1990) cointegration test can be employed. Table 3 reports, Trace and λ-max tests to identify number of cointegrating vectors.

Table 3: Johansen - Juselius likelihood cointegration tests

Hypothesis	Alternative	Trace Statistics	Critical Value 5%	$\lambda - \text{Max}$ Statistics	Critical Value 5%
r=0	r=1	81.667*	69.818	40.803*	33.876
r ≤1	r=2	40.863	47.856	20.262	27.584
r ≤2	r=3	20.600	29.797	11.273	21.131
r ≤3	r=4	9.3276	15.494	9.1775	14.264
r ≤4	r=5	0.1500	3.8414	0.1500	3.8414

Notes: * indicate significance at 5% level and r denotes number of cointegrating vectors. EViews 5.0 was used for all computations.

The null hypothesis of no cointegration (r=0) against the alternative of r ≤1, r≤2, r≤3, r≤4 is tested. Both tests show that there is one cointegrating vector present among the variables, and it can be concluded all the five variables, namely, real GDP, employment, real total R&D investment, real export and real gross domestic investment are cointegrated and follow a common long-run path.

4.2. Testing for Causality

As mentioned above, a five-variate Granger causality procedure developed by Toda and Yamamoto is used to determine the direction of causality. Table 4 reports the optimal lag length (k), VAR order ($k+d_{max}$), MWald statistics p values and direction of causality for five-variate VAR model. The results of the five-variate model are reported in Table 4 and can be summarized as follows. First, the results in Table 4 suggest that both null hypothesis of 'Granger no-causality from GDP to total R&D' and 'Granger no-causality from total R&D to GDP' can be rejected at the one percent significance level. This indicates that there is a two-way causality between real GDP and TRD. The fact that there is a two-way causality between GDP and TRD in the US economy indicates that TRD causes output, as argued in the literature, but output also causes TRD. Second, the causality between GDP and EMP, and GDP and INV, are all strong at one /or five percent significance level. This confirms the earlier finding that GDP is boosted by some internal factors.

Table 4: Toda and Yamamoto no-causality test five-variate VAR model results

Null Hypothesis	Lag(k)	k+d_{max}	MWald Statistics	p-values	Direction of Causality
GDP does not Granger Cause TRD	2	2+1=3	22.995***	0.000	GDP ↔ TRD
TRD does not Granger Cause GDP			8.331**	0.039	
GDP does not Granger Cause EXP	2	2+1=3	19.695***	0.000	GDP → EXP
EXP does not Granger Cause GDP			3.243	0.355	
GDP does not Granger Cause EMP	2	2+1=3	47.738***	0.000	GDP ↔ EMP
EMP does not Granger Cause GDP			10.825**	0.012	
GDP does not Granger Cause INV	2	2+1=3	31.829***	0.000	GDP ↔ INV
INV does not Granger Cause GDP			8.853**	0.031	

Notes: The (k+d_{max}) denotes VAR order. The lag length selection was based on LR: sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion. *** , ** and * denotes 1% and 5% , 10% significance level, respectively. → denotes one - way causality, ↔ denotes two - way causality. EViews 5.0 was used for all computations.

5. CONLUSIONS AND POLICY IMPLICATIONS

This study has employed the Johansen and Juselius (1990) cointegration test and the methodology of Granger no–causality test developed by Toda and Yamamoto (1995) to investigate the causality between economic growth and total R&D investment for the US. The tests are based upon annual time series data in a five variable VAR model for the period of 1960-2007. The results of cointegration test suggest that variables move together in the long run. Toda and Yamamoto causality test based on five-variate VAR model indicates a two-way causality between real GDP and total R&D investment. Feedback causality between real GDP and total R&D investment implies that the one consolidates the other. The evidence of a two-way causality between total R&D and GDP, suggest that if the US economy wants a sustainable economic growth, it should continue to increase its total R&D investment.

REFERENCES

1. Adams, J.D., Griliches, Z., (1996), "Research Productivity in a System of Universities," *NBER Working Papers Series,* No. 5833.
2. Aghion, P. and P. Howitt, (1992), "A Model of Growth through Creative Destruction. *Econometrica*," 60(2), pp.323-351.
3. Aiginer, K., Falk, M. (2005), "Explaining Differences in Economic Growth among OECD Countries," *Empirica,* 32, pp.19–43
4. Balassa, B., (1978), "Exports and Economic Growth: Further Evidence," *Journal of Development Economics* 5, pp.181–189.
5. Benum E. (2007), "Making Research Count: Norway and the OECD Connection," *Minerva*, pp. 365-387.
6. Braconier, H., (2000), "Do Higher Per Capita Incomes Lead to More R&D Expenditure? *Review of Development Economics*, 4 (3), pp.244–257.
7. Burney, N.A. (1996), "Exports and Economic Growth: Evidence from Cross-Country Analysis," *Applied Economic Letters*, 3, pp.369-373.
8. Cohen, W.M., Levinthal, D.A., (1989), "Innovation and Learning: The two Faces of R&D," *The Economic Journal*, 99, pp.569–596.
9. Dickey, D.A., and Fuller, W., (1981) "Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root," *Econometrica*, 49, pp.1057-1072.
10. Engle, R.F. and Granger C.W.J., (1987), "Cointegration and Error Correction: Representation, Estimation and Testing," *Econometrica*, 55, 1987, pp. 251-276.
11. Estrada, A., Montero, J., M. (2009), "R&D Investment and Endogenous Growth: A SVAR Approach," Banco De Espana, *Working Papers Series,* No. 0925.
12. Falk, M.(2007), "R&D Spending in the High-Tech Sector and Economic Growth," *Research in Economics*, 61, pp. 140–147
13. European Commission, (2008), "A Time Series Analysis of the Development in National R&D Intensities and National Public Expenditures on R&D," *Study Report*, Brussels, December 2008.
14. Feller, I., (1990), "Universities as Engines of R&D-Based Economic Growth: They Think They Can," *Research Policy* 19, pp.335–348.
15. Fraumeni, B.M., Okubo, S., (2002), "R&D in the National Income and Product Accounts: A First Look at its Effect on GDP," *Bureau of Economic Analysis Working Papers*, 2002-1.
16. Fosu, A.K. (1990), "Exports and Economic Growth: The African Case," *World Development*, 18,pp.831-835.

17. Goel, R.K., Payne, J.E., Ram, R. (2008), "R&D Expenditures and U.S. Economic Growth: A Disaggregated Approach," *Journal of Policy Modeling*, 30, pp. 237–250.

18. Granger, C. W. J. (1969), "Investigating Causal Relationships by Econometric Models and Cross-Spectral Models," *Econometrica*, 37(3), pp. 424–38.

19. Griffith R., Huergo E., Mairesse J., Peters B. (2006), "Innovation and Productivity Across Four European Countries," *Oxford Review of Economic Policy,* 22(4), pp. 483-498.

20. Griffith R., Redding S., Van Reenen J. (2004), "Mapping the two Faces of R&D: Productivity Growth in a Panel of OECD Industries," *Review of Economics and Statistics*, 86(4), pp. 883-895.

21. Griliches Z. (1994), "Productivity, R&D, and the Data Constraint," *American Economic Review*, 84(1), pp. 1-23.

22. Griliches, Z. (1992), "The Search for R&D Spillovers," *Scandinavian Journal of Economics* 94, pp. 29-47.

23. Griliches, Z., (1980), "R&D and Productivity Slowdown," *American Economic Review* 70, pp. 343–348.

24. Grossman, G. and E. Helpman, (1991a), *Innovation and Growth in the Global Economy*, Cambridge, MA: MIT Press.

25. Grossman, G. and E.Helpman, (1991b), "Quality Ladders and Product Cyles," *Quarterly Journal of Economics*, 106, pp.557-586.

26. Grossman, G. and E.Helpman, (1991c), "Quality Ladders in the Theory of Growth," *Review of Economic Studies*, 58, pp.43-61.

27. Grossman, G.M., and E. Helpman (1994), "Endogenous Innovation in the Theory of Growth," *Journal of Economic Perspectives*, 8, pp. 23-44.

28. Johansen, S., and Juselius, K., (1990), "Maximum Likelihood Estimation and Inference on Cointegration – with Applications to the Demand for Money," *Oxford Bulletin of Economics and Statistics*, 52, pp.169-210.

29. Jovanovic, B., Nyarko, Y., (1995), "Research and Productivity," *NBER Working Papers Series*, No. 5321.

30. Lichtenberg, F.R., (1992), "R&D Investment and International Productivity Differences," *NBER Working Paper Series*, No. 4161.

31. Madden, G., Savage, S.J., Bloxham, P., (2001), "Asian and OECD International R&D Spillover," *Applied Economics Letters*, 8, pp. 431–435.

32. Maloney, W., Rodriguez-Clare, A., (2007), "Innovation Shortfalls," *The World Bank Working Papers*, No. 4283.

33. Mansfield, E., (1988), “Industrial R&D in Japan and the United States: A Comparative Study,” *American Economic Review* 78, pp.223–228.

34. Mayhew K., Neely A. (2006), “Improving Productivity-Opening the Black Box,” *Oxford Review of Economic Policy,* 22(4), pp. 445-456.

35. OECD (1993), *The Measurement of Scientific and Technological Activities: Standard Practice for Surveys of Research and Experimental Development – Frascati Manual 1993*, OECD, Paris.

36. OECD (2003), *The Sources of Economic Growth in OECD Countries*, Paris.

37. OECD (2009), OECD Science, Technology and Industry Scoreboard 2009, OECDPublishing,doi:10.1787/sti_scoreboard-2009, http://dx.doi.org/10.1787/stiscoreboard-2009-en.

38. Pesaran, M. H., Shin, Y., and Smith, R. J. (2001), “Bounds Testing Approaches to the Analysis of Level Relationships,” *Journal of Applied Econometrics*, 16, pp. 289–326.

39. Pessoa, A. (2010), “R&D and Economic Growth: How Strong is the Link?,” *Economics Letters*, doi: 10.1016/j.econlet.2010.01.010

40. Phillips, Peter C. B., and Pierre Perron (1988), “Testing for a Unit Root in Time Series Regression.” *Biometrika* 75(2), pp.335–46.

41. Ram, R.(1985), “Exports and Economic Growth: Some Additional Evidence,” *Economic Development and Cultural Change*, 33, pp.415-25. Rambaldi, A.N. and Doran, H. (1996), “Testing for Granger non-causality in cointegrated systems made easy”, *Working Paper* in Econometrics and Applied Statistics No. 88, Department of Econometrics, University of New England, Armidale.

42. Romer, P., (1990), “Endogenous Technological Change,” *Journal of Political Economy* 98, pp.71-102.

43. Shan, J. Sun, F. (1999), “Export-Led Growth and the US Economy: Some Further Testing,” *Applied Economics Letters*, 6. pp.169-72.

44. Sheehey, E.J., (1992), “Exports and Growth: Additional Evidence,” *Journal of Development Studies* 28, pp.730–734.

45. Shirazi, N., S., Manap, T., A. (2005), “Export-Led Growth Hypothesis: Further Econometric Evidence from South Asia,” *The Developing Economies*, XLIII-4, December , pp. 472–88.

46. Sylwester, (2001), “R&D and Economic Growth,” *Knowledge, Technology, & Policy,* 13(4), pp. 71-84.

47. Toda, H. Y., and Phillips P. C. B. (1993), “Vector Autoregressions and Causality,” *Econometrica* 61(6), pp.1367–93.

48. Toda, H.Y., Yamamoto, T., (1995), "Statistical Inference in Vector Autoregressions with Possibly Integrated Processes," *Journal of Econometrics,* 66, pp.225–250.

49. Tyler, W.G. (1981), "Growth and Export Expansion in Developing Countries: Some Empirical Evidence," *Journal of Development Economics*, 3, pp. 337-49.

50. U.S. Department of Commerce, Bureau of Economic Analysis, http://www.bea.gov/national

51. Ulku H., (2007), "R&D, Innovation and Output: Evidence from OECD and non OECD Countries," *Applied Economics*, 39(3), pp.291–307.

52. Wang, E. C. (2010), "Determinants of R&D Investment: The Extreme-Bounds-Analysis Approach Applied to 26 OECD Countries," *Research Policy*, 39, pp. 103-116.