WP/04/185

IMF Working Paper

R&D, Innovation, and Economic Growth: An Empirical Analysis

Hulya Ulku

INTERNATIONAL MONETARY FUND

 WP/04/185

IMF Working Paper

Research Department

R&D, Innovation, and Economic Growth: An Empirical Analysis

Prepared by Hulya Ulku[1]

Authorized for distribution by Arvind Subramanian

September 2004

Abstract

This paper investigates the main postulations of the R&D based growth models that innovation is created in the R&D sectors and it enables sustainable economic growth, provided that there are constant returns to innovation in terms of R&D. The analysis employs various panel data techniques and uses patent and R&D data for 20 OECD and 10 Non-OECD countries for the period 1981–97. The results suggest a positive relationship between per capita GDP and innovation in both OECD and non-OECD countries, while the effect of R&D stock on innovation is significant only in the OECD countries with large markets. Although these results provide support for endogenous growth models, there is no evidence for constant returns to innovation in terms of R&D, implying that innovation does not lead to permanent increases in economic growth. However, these results do not necessarily suggest a rejection of R&D based growth models, given that neither patent nor R&D data capture the full range of innovation and R&D activities.

JEL Classification Numbers: O30; O31; O33; O47

Keywords: Innovation; R&D, patents; economic growth; total factor productivity; panel data; generalized method of moment (GMM)

Author(s) E-Mail Address: hulya.ulku@man.ac.uk

[1] This paper was prepared while the author was working in the Research Department. The author is grateful to Adam Jaffe, Tito Cordella and Ayhan Kose for their invaluable comments and suggestions.

Contents Page

Appendix Tables

Figures

I. INTRODUCTION

Recent theories of economic growth draw attention to endogenous technological change to explain the growth patterns of world economies. According to these so-called endogenous growth models, pioneered by Romer (1986), technological innovation is created in the research and development (R&D) sectors using human capital and the existing knowledge stock. It is then used in the production of final goods and leads to permanent increases in the growth rate of output. At the heart of these models is their postulation that endogenously determined innovation enables sustainable economic growth, given that there are constant returns to innovation in terms of human capital employed in the R&D sectors. This paper uses various panel data techniques and the data of 20 OECD and 10 non-OECD countries for the period 1981–97 to investigate the following postulations of R&D based endogenous growth models: (1) R&D investment increases innovation and there are constant returns to innovation; (2) innovation leads to permanent increases in per capita GDP.

The empirical studies of endogenous growth models generally involve testing the effect of R&D variables on total factor productivity (TFP) growth. For example, Jones (1995b) uses the time series plots of the TFP growth and the growth rate of the numbers of scientists and engineers in France, Germany, Japan and United States to test the validity of R&D based growth models. However, he finds no evidence that these variables are positively related. Aghion and Howitt (1998) provide explanations for the contradicting results of Jones (1995b). First, the increasing complexity of technology makes it necessary to raise R&D over time just to keep the innovation rate constant for each product. Second, as the number of products increases, an innovation in any one product affects a smaller proportion of the economy, and therefore, has a smaller proportional spillover effect on the aggregate stock of knowledge. They then argue that instead of the number of the scientists and engineers, GDP share of R&D investment should be used to take into account the size of the economy. Scherer (1982), Griliches and Lichtenberg (1984), Aghion and Howitt (1998), and Zachariadis (2003) provide strong evidence that in the U.S. economy R&D investment and TFP growth are positively related.

The positive relationship between countries' own R&D and productivity growth has been also confirmed by studies using international panel data, such as Frantzen (2000) and Griffith, Redding and Reenen (2002). There is also strong evidence that R&D spillovers from industrialized countries to developing countries have positive effects on the TFP growth of the latter (Coe, Helpman and Hoffmaister (1995); Griffith, Redding and Reenen (2002)). In a more recent study Savvides and Zachariadis (2003) show that both domestic R&D and foreign direct investment increase the domestic productivity and value added growth. Zachariadis (2003) compares the effect of R&D on aggregate and manufacturing output and finds that the effect of R&D is much higher for aggregate economy than the manufacturing sector.

Although R&D data have enabled growth economists to shed some light on endogenous growth theories, they alone do not allow us to analyze these models in depth. In particular, to examine the determinants of innovation that is the heart of endogenous growth theories, one needs data on both the input (R&D) and the output of an innovative activity. Porter and Stern (2000) is one of the first studies that utilized aggregate level patent data to examine the determinants and the effects of innovation. They find that innovation is positively related to human capital in the R&D sectors and national knowledge stock.[2] They also show that there is a significant but weak relationship between innovation and TFP growth. Although our study shares some common features with Porter & Stern (2000), its contribution to the existing literature is twofold: first, we examine the effect of innovation on per capita GDP of both developed (OECD) and developing (non-OECD) countries, while the existing studies use only a small sample of OECD countries; second, we use various econometrics techniques to increase the accuracy of our results. In addition, our analysis controls for a larger number of both innovation and production determinants such as technology spillovers, human capital, institutional quality, and trade liberalization.

The findings of the paper suggest that innovation has a positive effect on per capita outputs of both developed and developing countries. However, only the large market OECD countries are able to increase their innovation by investing in R&D and the remaining OECD countries seem to promote their innovation by using the know-how of other OECD countries. In particular, a 1 percent increase in innovation raises per capita income by around 0.05 percent in both OECD and non-OECD countries, while a 1 percent increase in R&D stock increases innovation by about 0.2 percent only in large market OECD countries, which includes the G-7. Although these results provide strong evidence for R&D based growth models as they suggest that innovation is endogenously created in the economy and it promotes economic growth, they lack the support for constant returns to innovation with respect to R&D. This implies that innovation, like capital stock, leads to only short term increases in the growth rate of output, and is not able to explain perpetual economic growth. However, as neither patent nor R&D data are complete measures of innovation, these results should not be interpreted as a rejection of the R&D based growth models.

The remainder of the paper is organized as follows: Section II introduces the model; Section III explains the data and methodology; Section IV documents the statistical properties of data and stylized facts; Section V presents the regression results; and Section VI concludes.

---

[2] Though the use of patent data in macroeconomic analysis of innovation is new, their use in microeconomic analysis is very common. For example, Schmookler and Brownlee (1962), Griliches and Schmookler (1963), Jaffe (1986, 1989), Ariel Pakes (1985), Hall, Griliches and Hausman (1986) and Hall, Jaffe, and Trajtenberg (2001, 2002) are the main contributors to the analysis of innovative activity using sector level patent data. Although there are some disadvantages of employing patent data to measure innovative activity, such as variation in the intrinsic value of patents and inability of patents to capture the whole range of innovation, they can be accounted for in the econometric models. See Comanor, and Scherer (1969), and Griliches (1990) for further details on the analysis of patent data as a measure of innovation. In addition, detailed analysis on the characteristics of R&D data can be found in Griliches (1994).

II. The Model

Our empirical model builds on the R&D based growth model of Romer (1990). Romer's model is based on three premises: (1) growth is driven by technological change; (2) technological change arises as a result of intentional actions taken by people who respond to market incentives; (3) blue prints (designs) used to produce new products are nonrival, i.e. they can be replicated with no additional cost. The model has three sectors: research and development (R&D) sector, intermediate goods sector and final output sector. The final output is produced according to Cobb-Douglas production function

$$Y(H_r, L, x) = H_Y^{\alpha} L^{\beta} \int_0^{\infty} x(i)^{1-\alpha-\beta} \, di \tag{1}$$

where, *H, L, x* are human capital, labor and producer durables, respectively. Each producer durable is produced by a monopoly in the intermediate goods sector using η units of forgone consumption and the design of that durable bought from R&D sectors.[3] The creation of new designs in R&D sector evolves according to the following equation

$$\dot{A} = \delta H_A^{\theta} A \tag{2}$$

where H_A is total human capital in R&D sector, A is knowledge stock and $\dot{A}$ is the new designs (technological change or innovation). The most crucial postulation of the Romer's model that leads to sustainable economic growth is the fact that production of new designs is linear in human capital employed in the R&D sectors and knowledge stock (i.e, $\theta = 1$). This has two implications: first, devoting more human capital to research leads to a higher rate of production of new designs; second, the larger the total stocks of designs and knowledge are, the higher the productivity of an engineer working in the research sector will be. After a new design is produced, it enters into an economy in two distinct ways: a new design enables the production of a new intermediate good that can be used to produce output; it also increases the total stock of knowledge and the productivity of human capital in the research sector. Total capital evolves according to the following equation:

[3] Unlike learning by doing model (Arrow, 1970) and spillover model (Lucas, 1988), Romer's model explains technological change by deliberate actions of profit motivated agents. In Romer's model R&D firms obtain patent rights for their designs, and then sell these patent rights to intermediate goods sector. Since the entry to R&D sector is free the profits of R&D firms are equal to zero. On the other hand, firms in the intermediate goods sector can have positive profits as the entry to this sector is restricted by monopoly power. For more details on the derivation of the demand and the profit function of the monopolistic intermediate goods sector and the solution of the model see Romer (1990) and Romer (1994).

$$\dot{K}(t) = Y(t) - C(t) \tag{3}$$

Because it takes η units of forgone consumption to create one unit of any type of durable, this accounting measure of K is related to durable goods that are actually used in production by the rule

$$K = \eta \sum_{i=1}^{\infty} x_i = \eta \sum_{i=1}^{A} x_i .$$

Because of the symmetry in the model, all available durable goods are supplied at the same level and can be denoted as x. Since A determines the range of durables that can be produced, and since η units of output are required per unit of durable goods, it is possible to solve for x from the equation that $K=\eta Ax$. Substituting $x=K/\eta A$ into the production function in equation (1) results in the final form of the production function in Romer's model

$$Y(H_Y, L, x) + (H_Y A)^{\alpha} (LA)^{\beta} (K)^{1-\alpha-\beta} \eta^{\alpha+\beta-1} \tag{4}$$

Increasing returns to scale arises in both R&D and final output sectors because both sectors use non-rival knowledge stock, A, as an input. A enters into the R&D sector directly and into the final good production process indirectly through knowledge spillovers. The most important implication of this model is that countries can attain perpetual economic growth by promoting R&D sectors and investing in human capital, which will be the main focus of this paper.

III. Description of Data and Methodology

The data consists of patent applications, gross R&D expenditure, and other macroeconomic data. Patent data is obtained from the NBER Patent Citations database. It includes all utility patent applications in manufacturing sectors made in the U.S. Patent and Trademark Office by the inventors residing in different countries. Utility patents are classified according to five main categories: chemical, computers and communication, drugs and medical, electrical and electronic and others.[4] The patent counts of each country for a given year are constructed by summing up all utility patent applications made by inventors' of that country.

[4] The category "others" include: agriculture-husbandry-food, amusement devices, apparel and textile, earth working and wells, furniture house fixtures, heating, pipes and joints, receptacles and the miscellaneous.

The patent stock is calculated using 20 percent depreciation rate as suggested in the literature.[5] The main reason for using the patent applications made in United States is to isolate the effects of different regulations in each country on the number of patent applications. In other words, in the U.S. Patent Office all inventors face the same regulations and quality control for their innovation, which reduces the amount of noise in data. The potential disadvantages of using U.S. patent applications such as distance from the United States, or the economic alliance with United States have been taken into account throughout the analysis. In addition, we used patent applications instead of granted patents as the time lag between the application year and grant year can be very long.

Gross R&D expenditure (GERD) data are obtained from the OECD Main Statistics and Technology Indicators database. It is defined as total expenditure on R&D performed on national territory during a given period, which includes the R&D performed within a country and funded from abroad but excludes payments made abroad for R&D. It comprises of R&D expenditure in business enterprises, government sector, higher education and non-profit firms. The series are deflated using the 1995 implicit price deflator and converted to US dollars using the monthly averages of the exchange rates obtained from the OECD database. The gaps in the data are interpolated by averaging the observations in the preceding and succeeding years. The stock of R&D expenditure (R&D stock) has been employed in the regression analyses to take into account the effects of past research efforts on innovation. The R&D stock has been constructed using 20 percent depreciation rate.

The remaining macroeconomic variables are obtained from the following databases: GDP, gross fixed investment, secondary school enrollments (WDI, 2002); labor population, imports and exports of manufacturing goods (OECD, 2002); openness in current prices (PWT.6); expropriation risk index (World Bank, International Country Risk Guide), and the U.S. trade share (IMF Direction of Trade Database (IMFDOT)). All variables are in constant 1995 U.S. dollars, with the exception of the variables that are the share of GDP, patent counts and the expropriation risk index. The expropriation risk index ranges from 1 to 10, which takes high values for low level of risk of expropriation.

Trade in manufacturing goods is calculated by summing up the values of imports and exports in constant 1995 U.S. dollars. Similarly, each country's GDP share of U.S. trade is calculated adding up the total exports and imports of United States to and from each partner country, and dividing this total by each country's GDP. The gross ratio of secondary school enrollment is measured as the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the level of secondary school education.

[5] The formula used to calculate initial patent stock level is $Ps_{t-1} = P_t/(r+\delta)$ where Ps is patent stock, P_t is patent flows at year *t, r* is the growth rate of patent flows, and δ is the depreciation rate of patents. The patent stock for subsequent years is calculated using the formula $Ps_t = P_t + (1-\delta)Ps_{t-1}$.

The series for secondary school enrollments are available for every five years. The gaps are interpolated using moving averages of the five-year observations.[6]

IV. Statistical Analysis of Data and Stylized Facts

This section examines the statistical properties of the data and presents some stylized facts about the main variables of the Romer's model, namely, per capita GDP, investment, R&D and patent applications. As seen from Table 1 and 2, data do not have unit root and heteroskedasticity (in most of the countries), though they exhibit first order autocorrelation. Throughout the analysis, the first order autocorrelation problem has been eliminated by either differencing the data or using Prais-Winsten estimation technique. The remainder of this section provides some stylized facts about the relationships among GDP, investment, R&D expenditure and patent applications.

Table 3 documents the rankings of the countries in terms of their average levels of GDP, investment, R&D and patent applications. As seen from Table 3, the G-7 countries are in the highest rank, while Greece, Portugal, Ireland, New Zealand and Iceland are in the lowest rank of all four variables. In addition, out of nine countries having both higher levels of GDP and investment, eight of them also have higher levels of R&D expenditure and patent applications, which suggests a positive correlation among these variables. To take into account the size of the economy, the countries are also ranked for per capita levels of the above variables. As Table 4 shows, Switzerland and Japan rank the highest, while Portugal, Greece, Spain, and Ireland rank the lowest in per capita levels of GDP, investment, R&D and patents. Of the ten countries ranking high in per capita patent, eight countries also rank high in per capita R&D expenditure, while seven countries rank high in per capita GDP. This again suggests positive relationships among per capita GDP, investment, patents and R&D.

To see how per capita levels and the growth rates of GDP, investment, R&D and patents behave across country groups with different income and market sizes, we also documented the averages of these variables in Figures 1 to 4 for the following country groups: OECD, non-OECD, large and small-market OECD, and high income and low-income OECD countries.[7]

---

[6] For example, if the observations in 1980 and 1985 are equal to 100 and 120, respectively, then the observation for 1981 is calculated as (100+120)/2=110, and the observation for 1982 is calculated as (110+120)/2. Our results are not sensitive to different types of interpolation.

[7] These samples are constructed using the rankings presented in Tables 3 and 4. Specifically, countries ranking the first nine (last nine) according to their aggregate GDP and investment levels have been referred to as larger market (smaller market) countries. Similarly, countries ranking the first nine (last nine) in terms of per capita GDP and investment have been referred to as higher income (lower income) countries. In addition, non-OECD sample has been included in the analysis wherever R&D data are not used. The lists of the countries in each sample are presented in Table 5.

Table 1. Levin-Lin-Chu Panel Data Unit Root Test[1]

	Full Sample[2]		OECD Sample[3]		Non-OECD Sample[4]	
	t-star	P > t	t-star	P > t	t-star	P > t
GDP	-3.29	0.00	-2.35	0.01	-2.52	0.01
Secondary school_2	-5.16	0.00	-3.51	0.00	-4.45	0.00
Patent stock_2	-4.76	0.00	-2.07	0.02	-1.63	0.05
Investment	-3.04	0.00	-1.78	0.04	-2.44	0.00
Openness	-1.88	0.03	-1.87	0.03	-2.44	0.01
Patent flows_2	-3.019	0.00	-5.91	0.00	-1.88	0.03
R&D stock_2	-8.33	0.00	0.16	0.56	--	--
Expropriation risk index	-8.62	0.00	-3.17	0.01	-3.82	0.00
Import/trade in manufacturing	-5.81	0.00	-2.42	0.01	-5.81	0.00
US trade/GDP	-3.20	0.00	-3.29	0.00	-1.69	0.05

Sources: GDP, investment, secondary school enrolments (WDI, 2002), employment (WEO, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) expropriation risk index (World Bank, International Country Risk Guide), import/trade in manufacturing sector (OECD, 2002).
All variables are in natural logs. Patent, GDP, Investment and R&D are normalized by labor series.
1/ t-star statistics is distributed as standard normal under the null hypothesis of nonstationarity.
2/All regressions are augmented by one lag and none of them include a constant except for US trade/GDP.
3/ All regressions except for investment and openness (which are augmented by four and two lags, respectively) are augmented by one lag. All regressions except for GDP and secondary schools (which include trend and no constant, respectively) include a constant and have no trend.
4/All regressions are augmented by one lag except for patent stocks. None of the regressions include a constant except for patent stock, investment and US trade/GDP all of which include a trend.

Table 2. Durbin-Watson and Heteroskedasticity Test, 1982–97[1]

Country	Heteroskedasticity Test H0: Constant Variance	Durbin Watson (d-statistic)[2]	Country	Heteroskedasticity Test H0: Constant Variance	Durbin Watson (d-statistic)
Argentina	3.07(0.08)	1.49	Italy	0.01(0.94)	1.09
Australia	2.18(0.22)	1.54	Japan	8.84(0.00)	1.63
Austria	2.79(0.10)	1.84	Malaysia	1.94(0.16)	2.02
Belgium	0.92(0.34)	1.60	Netherlands	0.26(0.61)	2.17
Brazil	0.21(0365)	2.09	New Zealand	0.24(0.61)	2.17
Canada	0.28(0.60)	2.53	Norway	0.03(0.85)	1.72
Denmark	0.15(0.70)	1.65	Philippines	3.31(0.07)	1.97
Finland	0.58(0.45)	1.98	Portugal	0.04(0.84)	1.46
France	1.16(0.28)	1.98	Singapore	3.16(0.08)	2.25
Greece	3.29(0.07)	2.39	South Africa	0.08(0.78)	2.14
Hong Kong	0.83(0.36)	2.11	Spain	1.15(0.28)	1.02
Iceland	4.42(0.03)	2.08	Sweden	2.00(0.15)	2.23
India	0.62(0.43)	2.10	Switzerland	0.98(0.32)	1.32
Indonesia	1.05(0.31)	2.36	United Kingdom	1.07(0.30)	2.20
Ireland	3.01(0.08)	2.60	Venezuela	0.90(0.34)	2.86

Notes: Figures in parenthesis are p values.
1/The heteroskedasticity test is applied to the predicted values of GDP, which are obtained from the regression equation of production function: GDP= $\alpha_0 + \alpha_1$ (investment) + α_2 (patent stock_2) + α_3 (secondary school_2) + α_4(openness) + α_5 (expropriation risk index) + e_t . GDP, investment, and patent stock are normalized by labor, and all variables are in natural logarithms.
2/ The values of d-statistics below or above 2 indicate the presence of first order autocorrelation.

Table 3. Rankings of Countries by Aggregate GDP, Investment, Patents, and R&D Expenditure, 1981–97

Rank	Investment		GDP		Patents		R&D Expenditure	
1	Japan	1,244,578	Japan	4,442,000	Japan	19,286	Japan	86,412
2	France	255,983	France	1,378,000	France	2,752	France	26,271
3	Italy	180,502	United Kingdom	980,700	United Kingdom	2,561	United Kingdom	21,551
4	United Kingdom	155,169	Italy	976,700	Canada	1,866	Italy	12,255
5	Spain	96,886	Canada	505,700	Switzerland	1,177	Canada	8,134
6	Canada	91,700	Spain	489,000	Italy	1,132	Sweden	6,236
7	Netherlands	67,539	Netherlands	346,000	Netherlands	858	Switzerland	5,825
8	Australia	64,334	Australia	304,100	Sweden	809	Netherlands	5,599
9	Switzerland	59,366	Switzerland	287,200	Australia	433	Australia	4,476
10	Austria	45,149	Belgium	245,100	Belgium	358	Spain	3,395
11	Belgium	40,851	Sweden	213,700	Austria	339	Belgium	3,048
12	Sweden	34,507	Austria	202,500	Finland	318	Finland	2,169
13	Norway	31,419	Denmark	159,500	Denmark	217	Austria	2,112
14	Finland	24,781	Norway	123,800	Spain	134	Denmark	2,012
15	Denmark	23,460	Finland	117,100	Norway	121	Norway	1,848
16	Greece	21,340	Greece	106,400	New Zealand	55	Greece	621
17	Portugal	20,469	Portugal	89,410	Ireland	51	Portugal	515
18	New Zealand	10,094	New Zealand	52,830	Greece	10	New Zealand	511
19	Ireland	8,889	Ireland	48,800	Portugal	5	Ireland	485
20	Iceland	1,229	Iceland	6,445	Iceland	4	Iceland	111

Note: GDP, Investment and R&D Expenditure are in millions 1995 U.S. dollars.

Table 4. Rankings of Countries by per capita GDP, Investment, Patents, and R&D Expenditure, 1981–97

Rank	Investment		GDP		Patents		R&D Expenditure	
1	Japan	10,153	Switzerland	42,824	Switzerland	176	Switzerland	870
2	Switzerland	8,863	Japan	36,138	Japan	157	Sweden	730
3	Norway	7,417	Denmark	30,889	Sweden	95	Japan	705
4	Austria	5,823	Norway	29,152	Canada	68	France	466
5	Finland	4,980	Austria	26,054	Finland	64	Iceland	442
6	Iceland	4,875	Iceland	25,492	Netherlands	58	Norway	436
7	Denmark	4,546	Sweden	24,996	France	49	Finland	436
8	France	4,539	Belgium	24,555	United Kingdom	45	Denmark	390
9	Netherlands	4,536	France	24,397	Austria	44	Netherlands	376
10	Belgium	4,096	Finland	23,507	Denmark	42	United Kingdom	375
11	Sweden	4,039	Netherlands	23,173	Belgium	36	Belgium	306
12	Australia	3,842	Canada	18,401	Norway	29	Canada	297
13	Canada	3,347	Australia	18,056	Australia	26	Austria	272
14	Italy	3,177	Italy	17,183	Italy	20	Australia	267
15	New Zealand	2,952	United Kingdom	17,040	New Zealand	16	Italy	216
16	United Kingdom	2,700	New Zealand	15,423	Iceland	15	New Zealand	150
17	Ireland	2,509	Ireland	13,729	Ireland	14	Ireland	137
18	Spain	2,504	Spain	12,617	Spain	3	Spain	88
19	Greece	2,106	Greece	10,487	Greece	1	Greece	61
20	Portugal	2,061	Portugal	9,005	Portugal	1	Portugal	52

Sources: GDP and Investment (WDI (2002)), R&D (OECD (2002)), Patents (NBER Patent Citation Database).
Notes: All series are in 1995 U.S. dollars and averaged over 1981–97, Patents are in per million people.

Table 5. List of the Countries in Each Sample

Full Sample	Non-OECD	OECD	Large-Market (OECD)	Small-Market (OECD)	High-Income (OECD)	Low-Income (OECD)
Argentina	Argentina	Italy	G-7	Austria	Switzerland	Canada
Australia	Brazil	Japan	Canada	Denmark	Japan	Australia
Austria	Hong Kong	Netherlands	France	Norway	Denmark	Italy
Belgium	India	New Zealand	Japan	Finland	Norway	United
Brazil	Indonesia	Norway	Italy	Greece	Austria	Kingdom
Canada	Malaysia	Portugal	United Kingdom	Portugal	Iceland	New Zealand
Denmark	Philippines	Spain		New Zealand	Sweden	Ireland
Finland	Singapore	Sweden	Others	Ireland	Belgium	Spain
Hong Kong	South Africa	Switzerland	Spain		France	Greece
France	Venezuela	United Kingdom	Netherlands			Portugal
Greece		Australia	Australia			
Iceland		Austria	Switzerland			
India		Belgium				
Indonesia		Canada				
Ireland		Denmark				
Italy		Finland				
Japan		France				
Malaysia		Greece				
Netherlands		Iceland				
New Zealand		Ireland				
Norway						
Philippines						
Portugal						
Singapore						
South Africa						
Spain						
Sweden						
Switzerland						
United Kingdom						
Venezuela						

Note: When dividing the OECD sample in sub samples, countries with high (low) aggregate GDP and investment are referred to as large (small) market countries, and countries with high (low) per capita income are referred to as high-(low) income countries. China is not included in the analysis, as it does not have the openness variable.

Figure 1 compares the average per capita levels of R&D expenditure and patent applications across the country groups. High income and large market OECD countries have the highest, while low income and small market OECD countries have the lowest per capita R&D expenditure and patent applications. This indicates that income level and market size are positively correlated with per capita R&D and patents, and that per capita R&D and patents are positively correlated. According to Figure 2, which documents the average growth rates of per capita R&D and patents for each country group, income level and the market size are positively associated with the growth rate of R&D expenditure, while they are negatively associated with the growth rate of patents. However, we still observe a positive relationship between the growth rates of per capita R&D and patents.

The average levels and the growth rates of per capita patent applications and GDP for the OECD and non-OECD countries are documented in Figures 3 and 4. According to Figure 3, high-income OECD countries have the highest per capita GDP and patents, while low-income OECD and non-OECD countries have the lowest per capita GDP and patent applications. Within the OECD countries the market size is positively associated with both per capita GDP and patent applications. However, as seen from Figure 4, the growth rates of these variables are negatively related with the income level and market size. In particular, the high income and the large market OECD have the lowest growth rates of these variables. Nonetheless, both the levels and the growth rates of per capita GDP and patents are positively related across country groups.

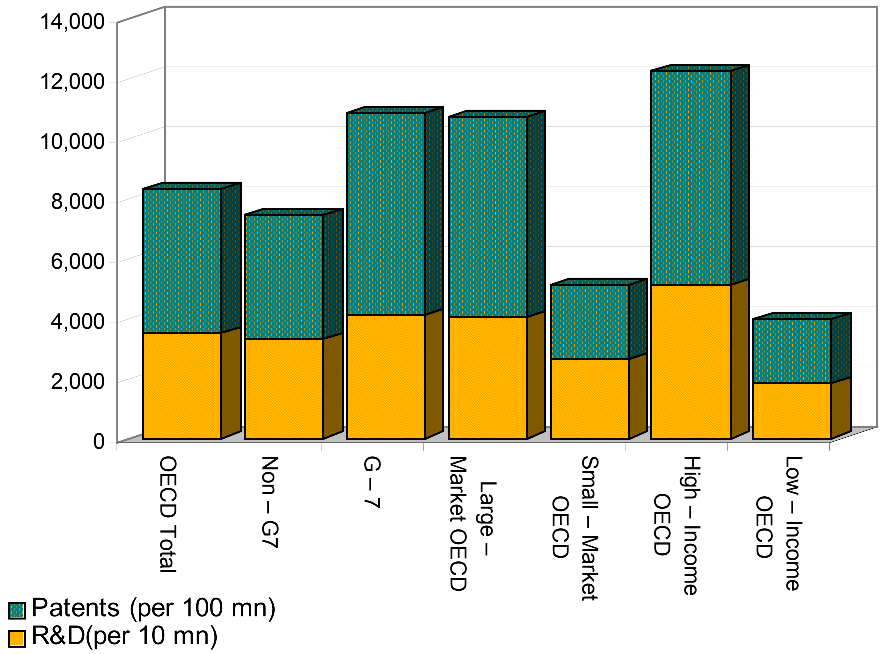
The time series plots of these variables also indicate that these variables move very closely over time in the majority of the countries (Figures 5 and 6). In brief, both the cross sectional and time series comparisons of per capita levels and the growth rates of GDP, investment, R&D and patent applications reveal that both the levels and the growth rates of these variables are positively correlated across countries and over time. These results are consistent with the premises of R&D based growth models that there is a positive association between R&D and innovation, and innovation and per capita GDP. The following section employs various panel data regression techniques, and provides more comprehensive analysis of the relationships among R&D, innovation and per capita GDP.

V. Empirical Analysis

The estimations of both innovation and production function have been carried out using fixed-effects and Arellano-Bond GMM estimators[8]. Each of these techniques has their own merits. The fixed-effects regression analysis accounts for country fixed effects and yields consistent estimators of the coefficients, provided that there is no endogeneity problem and the lagged dependent variable is not included in the analysis. The GMM analysis accounts for country fixed effects and yields consistent estimators in the presence of lagged dependent variable. In addition, by including instrumented lagged dependent variable in the analysis, to

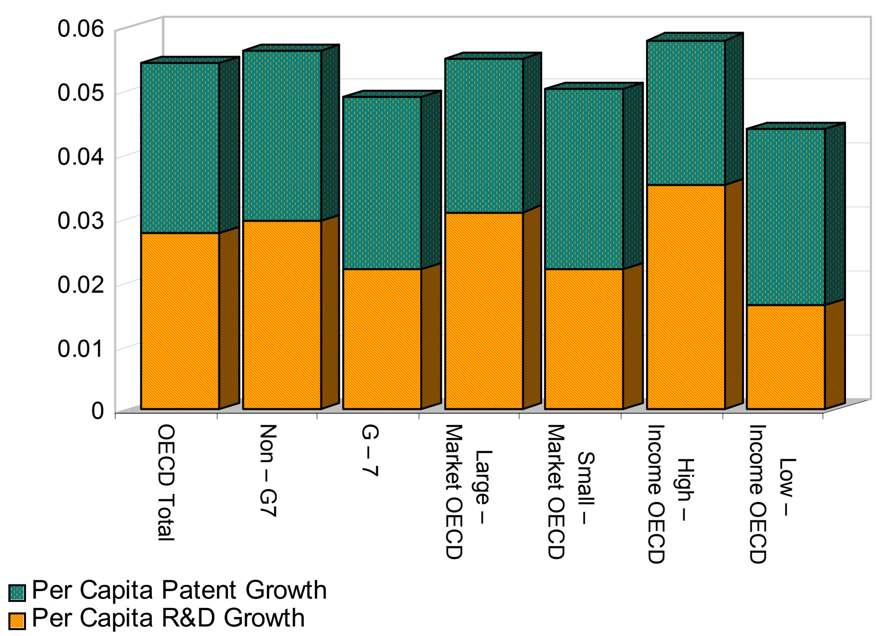
[8] In addition to the fixed effects and GMM analyses, OLS estimation has been carried out as well to provide a benchmark model.

Figure 1. Average Per Capita Patents and R&D, 1981-97



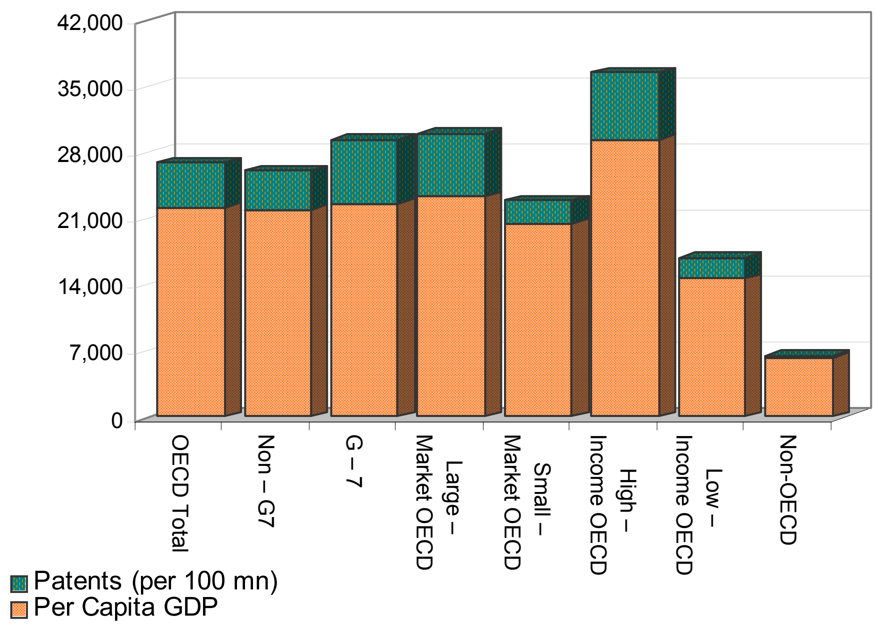
Sources: R&D Expenditure (OECD), patents (NBER Patent Citation)

Figure 2. Average Growth Rates of Per Capita Patents and R&D, 1982–97



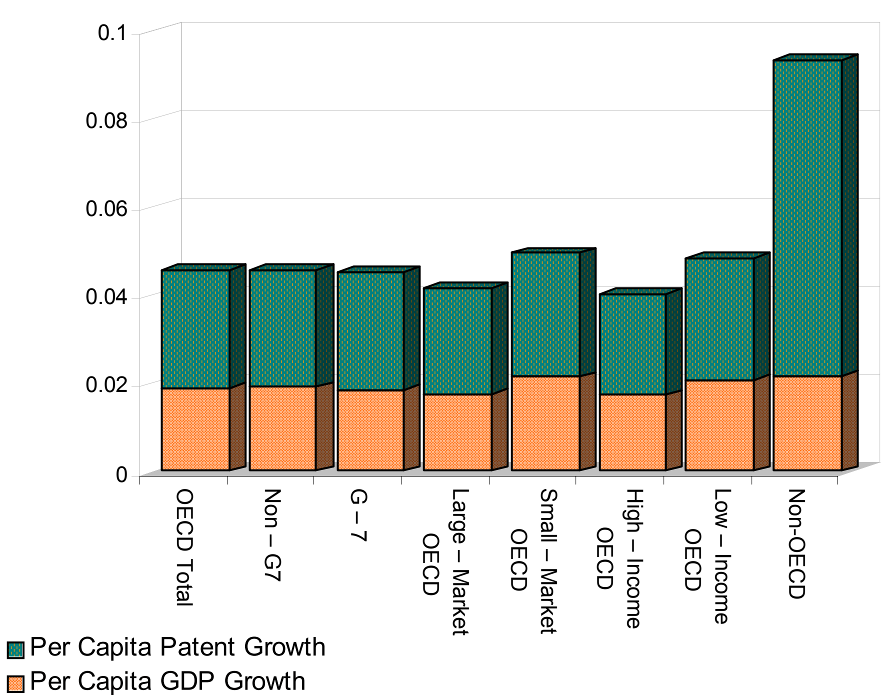
Sources: R&D Expenditure (OECD), patents (NBER Patent Citation).
Note : Growth rates are calculated as log differences of the series.

Figure 3. Average Per Capita GDP and Patents, 1981–97



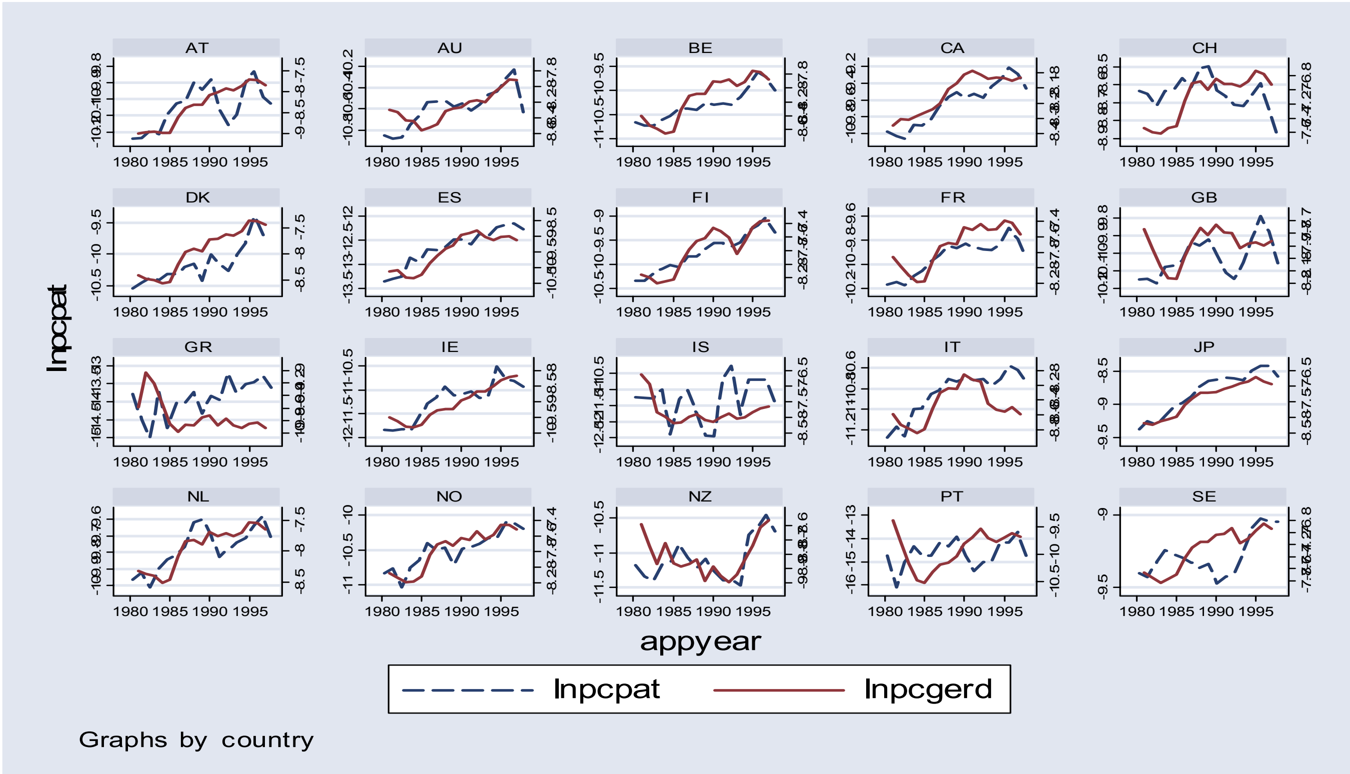
Sources: Patents (NBER Patent Citation), Investment, and GDP (WDI, 2002).

Figure 4. Average Growth Rates of Per Capita GDP and Patents, 1982–97



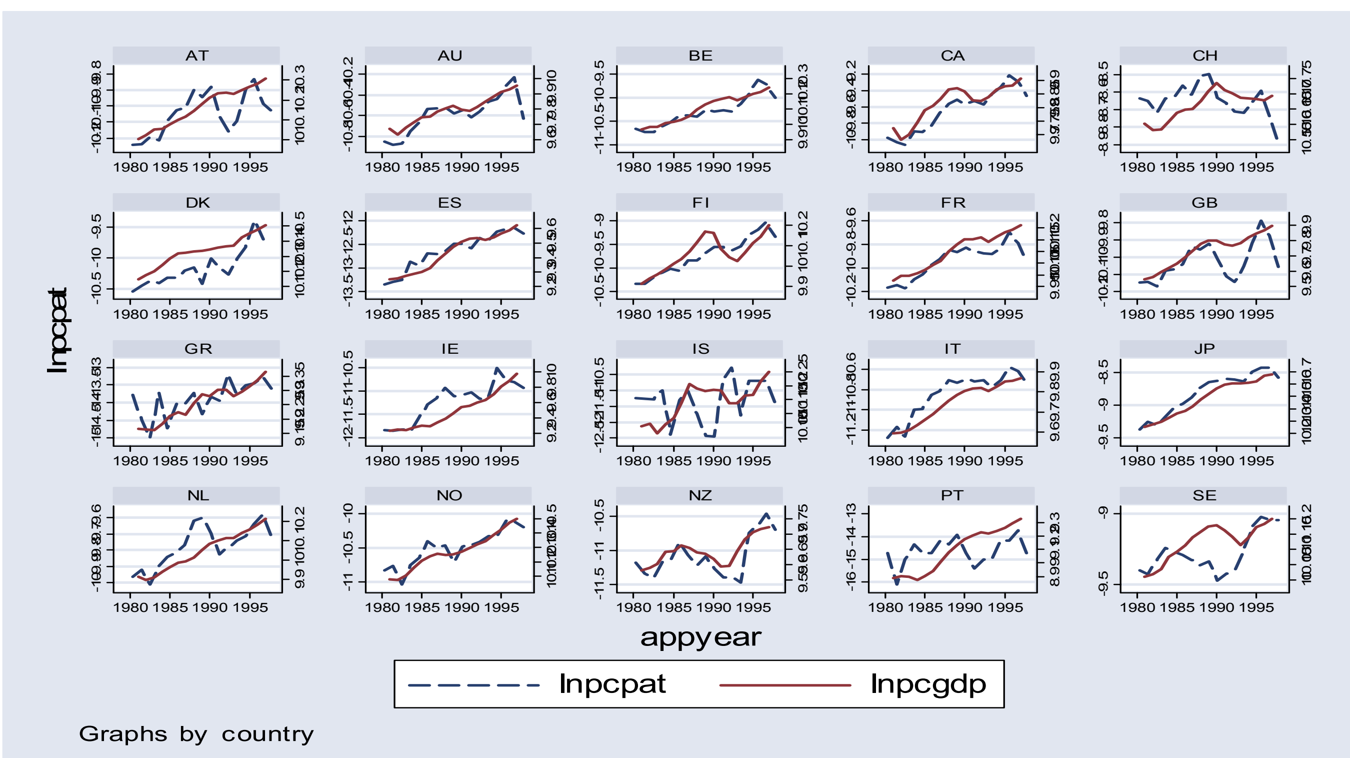
Sources: Patents (NBER Patent Citation), Investment, and GDP (WDI, 2002).
Note: Growth rates are calculated as log differences of the series.

Figure 5. Time-Series Plots of Per Capita Patent and R&D Expenditure, 1981–97



Sources: Patents (NBER Patent Citation), R&D Expenditure (OECD).

Figure 6. Time-Series Plots of Per Capita GDP and Patent Flows, 1981–97



Sources: GDP, population (WDI), Patents (NBER Patent Citation), R&D (OECD).
Note: See Appendix II, Table 17 for the list of the country codes.

some extent, GMM accounts for endogeneity problem.[9] However, since GMM uses the first differences of the series it might cause loss of information in the data. Therefore, the results of both estimations will be reported throughout the paper, though more focus will be given to GMM results. Furthermore, the first order autocorrelation problem has been accounted for either by employing the Prais-Winsten estimation technique, or using the first differences of the series. The time dummies have been included in all regressions to control for the time trend, and the common shocks to all countries. Moreover, to obtain accurate estimations of coefficients the empirical analysis has been undertaken for nine samples.[10]

A. Estimation of Innovation Function

This section investigates the postulation of R&D based growth models that technological innovation is created in the R&D sectors, and there are constant returns to innovation. Due to the scarcity of R&D data, the analysis has been conducted for 19 OECD countries from 1981 to1997. The regression equation is derived from equation (2) in Section II

$$\dot{A} = AH^{\theta} \tag{5}$$

where, $\dot{A}$ is flows of innovation (or knowledge flows, as in the Romer's model), A is the stock of innovation (or knowledge stock) and H is human capital devoted to R&D. The log linearized version of the above model is

$$Log(\dot{A}) = Log(A) + \theta \ Log(H). \tag{5'}$$

Equation (5′) tells us that a 1 percent increase in A and H increases innovation by 1 percent and θ percent, respectively. As mentioned in section II, in Romer's model, the magnitude of θ should be equal to 1 in order for the growth rate of output to grow continuously. This section is allocated for the estimation of θ and other determinants of innovation using international panel data from 19 OECD countries for the period 1981-1997.

---

[9] The GMM yields consistent estimators provided that data do not have AR (2) and the regressors are not correlated with the error term. The results of the AR (2) test and the Sargan test (which tests the correlation between regressors and the error term) are reported at the end of each GMM estimation results. For more technical details of this estimation see Arellano and Bond (1991), and Arellano-Bond Linear GMM Estimator in the reference book of STATA 8.

[10] These samples are: Full Sample, Non-OECD, and OECD. In addition, the OECD countries are grouped within themselves as low income, high income, small market and large market OECD countries. The reason for using these sub samples is to find out whether or not countries with different per capita incomes and market sizes behave differently in terms of the model. In addition, the results of the Chow test reveal that the coefficients are not constant across these groups, suggesting a separate analysis for each sample. See footnote 7 for the details on the construction of these samples.

In the empirical analysis of equation 5' the flows of innovation $(\dot{A})$ and human capital in the R&D sectors (*H*) are measured by patent applications (patent flows) and stock of R&D expenditure (R&D stock), respectively. Both patent flows and R&D stock have been normalized by labor series to control for the size of the economy. The knowledge stock, *A*, in equation 5' has not been accounted for directly in our regressions due to a lack of an independent measure for A.[11] However, it has been taken into account using different techniques: (1) instead of R&D expenditure we include stock of R&D expenditure (R&D stock) to proxy for knowledge accumulation over time as well as the human capital in the R&D sector; (2) the first lag of patent flows in the GMM analysis can serve as a an instrument for knowledge stock; (3) the differences in the initial levels of knowledge stock across countries are accounted for in both fixed effects and GMM analyses. Other control variables included in the regression analysis are expropriation risk, imports of manufacturing goods as share of total trade in manufacturing goods, and the share of U.S. trade in each country's GDP. The expropriation risk index captures the overall institutional quality of countries which takes higher values for lower risk of expropriation; the imports of manufacturing goods account for technology spillovers, and the share of U.S. trade controls for the effect of economic alliance with the United States on the numbers of the patent applications made in the U.S. Patent Office by the inventors of different countries. In addition, secondary school enrolments are included in the analysis to capture the effect of overall human capital of a country on its innovation level.

The results of the fixed-effects regression analysis are reported in Table 6. As seen from the Table, the coefficient of R&D stock is positive and significant in the G-7, other large market OECD countries, and the low-income OECD countries. According to these results a 1 percent increase in per capita R&D stock increases innovation by 0.40 percent in the G-7, and the large market countries, and 0.50 percent in low-income OECD countries.[12] Although secondary school enrollments have high t values in the large market and low-income OECD countries, it is not significant in any of the samples. Expropriation risk is significant only in the large market OECD countries, including G-7, while the U.S. share of GDP is significant in the G-7, large market OECD and low-income OECD countries only. In addition, the coefficient of the import share of trade in manufacturing goods is positive and significant the countries that do not have significant coefficient on R&D. This might suggest that countries that do not have effective R&D sectors are using the know how of other countries to increase their innovation.

---

[11] The patent stock variable could be a good candidate for knowledge stock. However, since patent stock and the R&D investment are highly correlated, inclusion of the patent stock as a regressor leads to a multicollinearity problem.

[12] See Appendix I, Table 12 for OLS regression results. Similar to the fixed effects results, the relationship between R&D expenditure and innovation is positive only in the G7 and large market countries. However, different from the fixed effects results, the coefficient of R&D stock is negative and significant in the full, non-G-7 and the small market samples, which could be attributed to the the fact that OLS results are biased in the presence of country fixed effects.

Table 6. Fixed Effects Regression Analysis of Per Labor Patent Flows, 1981–97

	Full	Non-G-7	G-7	Large Market	Small Market	High-Income	Low-Income
Second lag of R&D stock	0.135	0.086	0.389	0.414	0.126	0.121	0.516
	(1.70)	(0.88)	(7.04)	(8.19)	(1.00)	(1.23)	(4.36)
Second lag of Secondary school	-0.292	-0.219	0.082	0.136	-0.157	0.153	0.375
	(1.36)	(0.81)	(0.66)	(1.49)	(0.35)	(0.37)	(1.46)
Expropriation risk Index	-0.022	-0.286	0.649	1.090	-0.724	-1.668	0.754
	(0.05)	(0.52)	(2.29)	(5.74)	(0.77)	(1.86)	(1.55)
Manufacturing import/trade	1.925	2.056	-0.423	0.151	3.677	3.288	0.359
	(3.46)	(2.95)	(1.27)	(0.74)	(3.51)	(3.76)	(0.57)
U.S. trade/GDP	-0.043	-0.089	0.406	0.158	-0.165	-0.542	0.396
	(0.32)	(0.53)	(4.52)	(2.10)	(0.67)	(2.59)	(2.30)
Openness	-0.252	-0.122	-0.162	0.030	-0.248	-0.590	-0.392
	(0.89)	(0.30)	(1.30)	(0.26)	(0.41)	(1.35)	(1.11)
R squared	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Observations	285	210	75	135	120	135	120
Number of ifs	19	14	5	9	8	9	8

Sources: R&D stock (OECD, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) employment (WEO, 2002), expropriation risk index (World Bank, International Country Risk Guide), import/trade (OECD, 2002), U.S. trade (IMF Direction of Trade Database).

Notes: z statistics in parentheses. All variables are in natural logs and normalized by labor. All regressions include time dummies. Greece is not included in the analysis, as it does not have data on imports in manufacturing sector.

Table 7 reports the results of the Arellano-Bond GMM estimation, which, to some extent, takes into account endogeneity problem by including instrumented lagged dependent variable in the analysis. As seen from Table 7 the results are very similar to the ones obtained in the fixed effects analysis. The coefficient of R&D stock is significant only in large-market OECD, including G-7 and low-income OECD countries. According to these results, a 1 percent increase in R&D stock leads to around 0.20 percent increase the large market OECD countries including the G-7, and 0.30 percent increase in low income OECD. The fact that the coefficient of R&D stock is significant in the G-7 and the large market OECD countries provides support for the models that emphasize the importance of market size in promoting R&D sectors and innovation, Griliches (1957) and Acemoglu and Linn (2003). However, driving force behind the significant relationship between R&D stock and innovation in low-income OECD countries is not clear as this group includes both large market (UK, Canada, Italy, Australia and Spain) and small market (New Zealand, Ireland and Portugal) OECD countries. Table 8 reports the results of the regression analysis for the sub groups of low-income OECD countries in terms of their market sizes. As seen from Table 8, only the large market countries have significant coefficient on R&D stock. Although the sample size is not large enough to draw strong conclusions, the results reported in Table 8 are consistent with our hypothesis that market size is an important factor for the effectiveness of R&D sectors.

Another important observation from Table 7 is that the most of the countries that do not have effective R&D sectors have significant coefficient on import share of trade in manufacturing goods. This might imply that these countries import the know-how of other OECD countries to promote their innovation, instead of investing in formal R&D sectors. [13] Among the other control variables, secondary school enrollments seem to have an important effect on innovation in the G-7 countries only; economic alliance with the United States and the openness do not seem to matter in terms of the numbers of patent applications made in the United States, while institutional quality matters only in the OECD countries with large markets. In addition, the coefficient of the first lag of patent flows is positive and significant in all of the countries, with the magnitude of around 0.3 percent. This suggests that the knowledge flows of the previous year have a strong positive effect on the current innovation level, as suggested by Romer's model.[14]

---

[13] Different measures of technology spillovers across countries have been employed as well, such as foreign direct investment inflows, the R&D and patent stock of other countries multiplied by the trade share of each country, imports of manufactured goods as share of GDP. However, none of these measures yield significant coefficients. Only the imports in manufactured goods as share of trade in manufactured goods have a significant coefficient and expected sign.

[14] If the first lag of patent flows in this regression is taken as an instrument for knowledge stock, A, in Romer's model, then it means that a one percent increase in knowledge stock leads to 0.3 percent increase in innovation.

Table 7. General Methods of Moments (GMM) Regression Analysis of Per Labor Patent Flows, 1981–97[1]

	Full	Non-G-7	G-7	Large Market	Small Market	High Income	Low Income
Second lag of R&D stock	0.080 (0.94)	0.015 (0.14)	0.162 (2.52)	0.231 (3.44)	0.073 (0.53)	0.130 (1.06)	0.298 (3.09)
Second lag of Secondary school	0.039 (0.17)	-0.012 (0.04)	0.184 (1.84)	0.104 (1.06)	-0.169 (0.35)	0.362 (0.83)	0.047 (0.20)
Expropriation risk Index	-0.314 (0.63)	-0.522 (0.89)	0.297 (1.02)	0.455 (1.90)	-0.715 (0.72)	-0.289 (0.29)	0.356 (0.71)
Manufacturing import/trade	1.844 (2.89)	1.761 (2.17)	-0.315 (1.04)	0.178 (0.81)	2.633 (2.29)	4.226 (3.72)	0.057 (0.09)
U.S. trade/GDP	-0.066 (0.38)	-0.164 (0.80)	0.340 (3.77)	0.154 (1.75)	-0.095 (0.32)	-0.650 (2.28)	0.339 (1.96)
Openness	-0.169 (0.52)	0.034 (0.08)	-0.171 (1.42)	-0.046 (0.43)	-0.323 (0.51)	-0.583 (1.17)	-0.697 (2.05)
First lag of per labor patent	0.297 (4.26)	0.304 (3.72)	0.309 (2.42)	0.576 (6.99)	0.228 (2.36)	0.191 (1.94)	0.317 (3.89)
Second lag of per labor patent	-0.178 (2.71)	-0.188 (2.44)	0.354 (2.80)	--	-0.178 (1.89)	-0.187 (1.92)	--
Third lag of per labor patent	0.135 (2.01)	0.133 (1.66)	--	--	--	0.359 (3.28)	--
Constant	0.030 (3.05)	0.005 (0.27)	0.071 (2.23)	-0.024 (5.59)	0.062 (3.66)	-0.122 (1.05)	0.010 (0.89)
Sargan test[2] (*p-value*)	0.00	0.09	1.00	1.00	0.96	0.99	0.93
AR(2) test[3] (*p-value*)	0.38	56	0.56	0.27	0.62	0.38	0.37
Observations	247	182	70	126	112	117	112
Number of countries	19	14	5	9	8	9	8

Sources: R&D stock (OECD, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) employment (WEO, 2002), expropriation risk index (World Bank, International Country Risk Guide), import/trade (OECD, 2002), U.S. trade (IMF Direction of Trade Database).

Notes: Absolute values of z statistics are in parentheses. All variables are normalized by labor and log differenced. Greece is not included in the analysis, as it does not have data on imports in manufacturing sector.
1/ To eliminate the first order autocorrelation problem and the serial correlation between residuals and the regressors different lag lengths of the dependent variable are included in the analysis of different groups. For example, in large market and low income country groups it was sufficient to include one lag of the dependent variable, whereas in the small market countries three lags were needed to eliminate first order autocorrelation and endogeneity problem. It should also be noted that the inclusion of the different lag lengths is important only to solve autocorrelation and endogeneity problem and it does not have an effect on the sign and the significance of the coefficients of the explanatory variables.
2/ H_0: regressors are not correlated with the residuals.
3/ H_0: errors in first difference regression exhibit no second order serial correlation.

Table 8. General Methods of Moments (GMM) Regression Analysis of Per Labor Patent Flows, 1981-1997

	Low Income OECD	
	Large Market	Small Market
Second lag of R&D stock	0.513	-0.423
	(4.50)	(1.01)
Second lag of Secondary school	-0.072	0.993
	(0.59)	(1.28)
Expropriation risk Index	0.378	-0.808
	(1.24)	(0.41)
Manufacturing import/trade	0.056	4.292
	(0.20)	(1.22)
U.S. trade/GDP	0.516	0.715
	(3.90)	(1.09)
Openness	-0.686	-0.195
	(2.42)	(0.15)
First lag of per labour patent	0.299	0.176
	(2.40)	(1.01)
Constant	-0.001	-0.001
	(0.17)	(0.04)
Sargan test[1] (*p-value*)	1.00	1.00
AR(2) test[2] (*p-value*)	0.19	0.34
Observations	70	42
Number of countries	5	3

Sources: R&D stock (OECD, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) employment (WEO, 2002), expropriation risk index (World Bank, International Country Risk Guide), import/trade (OECD, 2002), U.S. trade (IMF Direction of Trade Database).

Notes: Absolute value of z statistics in parentheses. All variables are in natural logarithms, and normalized by labor. Greece is not included in the analysis, as it does not have data on imports in manufacturing sector.
1/ H_0: regressors are not correlated with the residuals
2/ H_0: errors in first difference regression exhibit no second order serial correlation.

In brief, the results obtained from the analysis of the relationship between R&D stock and innovation (patent applications) allows us to make the following conclusions: first, R&D intensity changes across countries with different market sizes and income levels[15]; second, only the large market OECD countries, which include the G-7 and some low-income OECD countries, seem to increase their innovation by investing in R&D sectors; third, there are no constant returns to innovation; fourth, technology spillovers have significant effects on the innovation of countries which do not have efficient R&D sectors. These results are consistent with the premises of R&D based growth models that innovation is endogenously created. However, they do not provide support for constant returns to innovation. This could be because our data is not able to capture the full range of innovation activities.

B. Estimation of Production Function

This section is allocated to the analysis of the relationship between innovation and per capita GDP. Equation (3) in Section II is the basis of our regression analysis

$$Y(H_Y, L, x) = (H_Y\, A)^{\alpha}\, (LA)^{\beta}\, (K)^{1-\alpha-\beta}\, \eta^{\alpha+\beta-1} \qquad (6)$$

where, *Y, L, H,* and *A* are total output, labor, human capital and the knowledge stock of economy, respectively. Here *K* includes both physical investment and new products. Production function presents constant returns to scale in its inputs *L, H* and *K*. increasing returns to scale arises because of the knowledge stock that enters the production function through new products and spillovers from R&D sectors. When deriving the regression equation from the above model, all variables are normalized by labor series[16]; composite investment, K, decomposed into new products, and physical investment, and the equation has been log linearized. The resulting regression equation is shown below

$$y_t = \alpha\, h_t + \gamma\, i_t + (1-\alpha-\gamma)\, \chi_t + \varepsilon_t \qquad (6')$$

where *yt, it,* and *xt* are per labor output, investment and new products, respectively; *ht* is the human capital as share of population. The investment, new product and human capital are measured by the gross fixed investment, stock of patent applications from the U.S. Patent Office, and the secondary school enrollments as share of the population who are in secondary school age, respectively. In addition to the variables in the regression equation above, risk

---

[15] This has also been confirmed by the Chow test. According to this test we reject the hypotheses that the coefficients are the same across samples.

[16] The reason for using labor series (i.e. instead of population) to normalize data is to eliminate multicollinearity problem caused by the high correlation between labor and investment.

of expropriation and openness variables are included in the analysis as well. The risk of expropriation index captures the overall institutional development, which takes higher values for lower risk of expropriation, and the openness variable approximates the degree of trade liberalization. Data include 20 OECD countries and 10 non-OECD countries for the period 1981–97.

The fixed-effects regression results are presented in Table 9. As seen from the table, the coefficient of patent stock is positive and significant in all samples, except for the G-7. According to these results, non-OECD countries have the highest returns to their patent stock with a magnitude of 0.11, while the small market OECD countries have the lowest returns, with a magnitude of around 0.06. All other countries have around 0.07 percent increase in their per capita GDP as a result of a 1 percent increase in their patent stock. Returns to investment are positive and significant in all samples, with the magnitudes ranging from 0.24 in the high income OECD countries to 0.37 in the non-OECD countries. Although the coefficient of secondary school enrollments has the expected sign and high t values in most of the samples, it is statistically significant only in the low-income OECD countries, with the magnitude of 0.08. As expected, the coefficient of openness and risk of expropriation variables are positive and significant in most of the samples, implying that trade liberalization and institutional quality are important determinants of the per capita income levels of countries.[17]

Table 10 reports the results of the GMM estimation. Similar to the fixed effects results, the coefficient of patent stock is positive and significant in all samples, except for the G-7.[18] Different from the fixed effects regression results, large market and high-income OECD countries have higher returns to their patent applications (0.06 percent) compared to the rest of the samples (0.04 percent). Similarly, returns to investment are positive and significant in all samples. For example, a 1 percent increase in investment increases output by around 0.10 percent in the high income, low income and small market OECD countries; 0.17 percent in the non-G-7, non-OECD and large market OECD countries; 0.20 percent in the OECD, and 0.25 percent in the G-7 countries. Returns to schooling are not significant in any of the samples, presumably as a result of the small variation in this variable over time.[19]

[17] See Appendix I, Table 13 for OLS regression results. According to the pooled OLS results, returns to investment are positive and significant in all samples, while returns to patent stock are significant only in the full, OECD and non-OECD samples. In addition, the risk of expropriation and openness variables are significant with the expected signs in most of the samples, while the secondary school enrollment is not significant in any of the samples.

[18] The reason that patent stock is not significant in the G-7 might be because of the small size of this sample.

[19] Though the coefficient of secondary school enrollment is negative and significant in the full and the OECD sample, the model for these samples suffers from the serial correlation between regressors and the residuals, as indicated by the low p values of the Sargan test.

Table 9. Fixed Effects Regression Analysis of Per Labor GDP, 1981–97

				Sub-samples of OECD					
	Full Sample	Non-OECD	OECD	Non-G-7-	G-7	Large Market	Small Market	High Income	Low Income
Investment	0.312	0.365	0.274	0.268	0.296	0.288	0.262	0.239	0.254
	(24.46)	(17.72)	(16.79)	(14.49)	(7.39)	(8.30)	(9.86)	(9.29)	(8.86)
Second lag of patent stock	0.104	0.111	0.076	0.074	0.023	0.071	0.044	0.059	0.098
	(9.18)	(6.44)	(4.94)	(4.16)	(0.87)	(2.86)	(1.70)	(2.63)	(3.47)
Second lag of secondary school	0.009	-0.198	0.010	0.012	0.016	0.018	0.032	-0.025	0.084
	(0.41)	(2.91)	(0.53)	(0.51)	(0.54)	(0.73)	(0.99)	(0.60)	(3.47)
Openness	0.025	-0.034	0.071	0.111	-0.040	-0.026	0.133	0.009	0.127
	(1.43)	(1.39)	(2.90)	(3.43)	(1.58)	(0.96)	(3.01)	(0.24)	(3.50)
Expropriation Risk	-0.025	-0.025	0.131	0.144	0.174	0.097	0.063	0.196	0.140
	(1.72)	(1.04)	(4.66)	(4.67)	(2.09)	(1.63)	(1.75)	(2.42)	(4.80)
R-squared	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Observations	449	149	300	225	75	135	135	135	135
Number of countries	30	10	20	15	5	9	9	9	9

Sources: R&D stock (OECD, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) employment (WEO, 2002), corruption index (World Bank, International Country Risk Guide), import/trade (OECD, 2002), U.S. trade (IMF Direction of Trade Database).

Notes: All variables are in natural logs and normalized by labor. All regressions include time dummies. Greece is not included in the analysis, as it does not have data on imports in manufacturing sector.
z statistics in parentheses.

Table 10. General Methods of Moments (GMM) Regression Analysis of Per Labor GDP, 1981–97

	Full Sample	Non-OECD	OECD	Sub-samples of OECD Non-G-7-	G-7	Large Market	Small Market	High Income	Low Income
Investment	0.206 (11.82)	0.173 (6.54)	0.194 (9.44)	0.155 (6.51)	0.253 (5.34)	0.169 (5.14)	0.123 (4.05)	0.098 (4.29)	0.082 (2.44)
Second lag of patent stock	0.040 (3.35)	0.038 (1.84)	0.058 (4.17)	0.048 (2.92)	0.002 (0.09)	0.057 (2.42)	0.042 (1.99)	0.059 (3.39)	0.042 (1.60)
Second lag of secondary school	-0.044 (2.06)	-0.055 (1.05)	-0.050 (2.59)	-0.032 (1.42)	0.029 (0.89)	0.023 (1.15)	-0.037 (1.17)	-0.010 (0.30)	0.029 (1.13)
Openness	0.056 (3.74)	-0.012 (0.51)	0.135 (6.14)	0.140 (4.71)	-0.019 (0.75)	-0.033 (1.68)	0.155 (4.21)	0.069 (2.15)	0.091 (2.61)
Expropriation risk	-0.048 (3.74)	0.023 (0.98)	0.037 (1.76)	0.048 (1.99)	0.192 (2.20)	0.106 (1.81)	0.036 (1.16)	0.060 (0.94)	0.050 (1.75)
First lag of GDP	0.447 (7.52)	0.582 (6.29)	0.542 (8.71)	0.654 (8.82)	0.267 (2.47)	0.484 (5.49)	0.702 (7.10)	0.781 (8.21)	0.740 (7.39)
Second lag of GDP	-0.042 (0.85)	0.026 (0.27)	-0.036 (0.74)	-0.083 (1.38)	0.212 (1.94)	-0.113 (1.40)	-0.034 (0.41)	-0.169 (2.02)	-0.013 (0.14)
Third lag of GDP	-0.081 (1.67)	-0.227 (2.31)	--	--	--	--	--	--	--
Fourth lag of GDP	0.188 (5.36)	0.268 (4.07)	--	--	--	--	--	--	--
Constant	0.025 (4.69)	0.049 (4.00)	0.006 (2.75)	0.002 (1.79)	0.001 (0.45)	0.001 (0.34)	0.003 (1.03)	0.006 (0.63)	-0.004 (1.20)
Sargan test[1] (*p-value*)	0.00	0.12	0.02	0.10	1.00	0.32	0.99	0.76	0.80
AR(2) test[2] (*p-value*)	0.57	0.84	0.42	0.35	0.48	0.32	0.36	0.90	0.58
Observations	359	119	280	210	70	126	126	126	126
Number of countries	30	10	20	15	5	9	9	9	9

Sources: GDP, investment, secondary school enrolments (WDI, 2002), employment (WEO, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) expropriation risk index (World Bank, International Country Risk Guide).

Notes: Absolute value of z statistics in parentheses. All variables are log differenced once. GDP, investment, and patent stock normalized by labor. All regressions include time dummies.
1/ H_0: regressors are not correlated with the residuals.
2/ H_0: errors in first difference regression exhibit no second order serial correlation.

Not surprisingly, the effect of trade liberalization on per labor GDP is positive and significant in all samples except for the G-7, large market OECD, and non-OECD countries. Specifically, a 1 percent increase in the openness variable is associated with about a 0.14 percent increase in per labor GDP in the non-G-7 and the OECD countries with small markets; and about a 0.09 percent increase in the high income and low-income OECD countries. Similarly, the coefficient of the expropriation risk index has the expected sign and significant in most of the samples with the highest magnitude in the G-7 and large market OECD countries, 0.20 and 0.11, respectively.

Additional to the analysis of the relationship between GDP and innovation, the relationship between total factor productivity (TFP) and innovation has been examined as well. As Table 11 shows, coefficient of patent stock is significant only for non-OECD countries, suggesting that in this sample innovation increases per capita GDP partly through its effect on TFP. The results for the full and the OECD samples are not conclusive as the model for these samples have been rejected by the sargan test.

VI. Conclusion

The objective of this paper was to assess whether there is a significant relationship between countries' R&D efforts and their innovation and between innovation and per capita income, as postulated by R&D based endogenous growth models. Our results show that there is a strong positive relationship between innovation (patent stock) and per capita GDP in both OECD and non-OECD countries, while only the OECD countries with larger markets, which include the G-7, Australia, Netherlands, Spain, and Switzerland, are able to increase their innovation by investing in R&D. The fact that only the large market OECD countries promote their innovation by investing in R&D provides support for the theories emphasizing the importance of market size for effective R&D sectors, Acemoglu and Linn (2003). The results also suggest that the OECD countries that do not have effective R&D sectors seem to promote their innovation through technology spillovers from other OECD countries.

In addition, while our analysis lends support for endogenous growth theories in that it confirms a significant relationship between R&D stock and innovation, and between innovation and per capita GDP, it lacks the evidence for constant returns to innovation in terms of R&D stock. This implies that R&D models are not able to explain sustainable economic growth, i.e. they are not fully endogenous. However, this deserves some explanations. First, given that neither patent nor R&D data are complete measures of innovation and research activities, our results should not be interpreted as a rejection of R&D models. Second, even there are diminishing returns to innovation in terms of R&D, as suggested by our results, R&D models can still explain long term growth as long as there are constant returns to produced factors such as capital, innovation, and knowledge stock, Aghion and Howitt (1998).

Table 11. General Methods of Moments (GMM) Regression Analysis of Total Factor Productivity (TFP), 1981–97

	Full	OECD	Non-OECD
First lag of TFP	0.789	0.876	0.726
	(19.66)	(22.13)	(12.10)
Second lag of patent stock	0.012	0.016	0.035
	(1.53)	(1.25)	(2.58)
Second lag of secondary school	0.029	0.021	0.025
	(1.54)	(1.31)	(0.67)
Openness	0.001	0.019	0.005
	(0.11)	(1.00)	(0.28)
Expropriation risk	-0.038	-0.060	-0.006
	(3.40)	(2.64)	(0.29)
Constant	0.001	0.000	-0.001
	(1.25)	(0.59)	(0.67)
Sargan test[1] (*p-value*)	0.00	0.08	0.28
AR(2) test[2] (*p-value*)	0.53	0.74	0.50
Observations	419	280	139
Number of countries	30	20	10

Sources: GDP, investment, secondary school enrolments (WDI, 2002), employment (WEO, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) expropriation risk index (World Bank, International Country Risk Guide), TFP (author's calculation: TFP = log (GDP) - 0.4 log (investment) - 0.6 log (employment).

Notes: Absolute value of z statistics in parentheses.
TFP is calculated by subtracting the log levels of labor and investment multiplied by their shares of income, which are assumed to be 0.6 and 0.4, respectively. All variables are log differenced once. Patent stock is normalized by labor. All regressions include time dummies.
1/ H_0: regressors are not correlated with the residuals.
2/ H_0: errors in the first difference regression exhibit no second order serial correlation.

I. Regression Tables

Table 12. Ordinary Least Square (OLS) Regression Analysis of Per Labor Patent Flows, 1981–97

	Full	Non-G-7	G-7	Large Market	Small Market	High Income	Low Income
Initial patent flows	1.118	1.046	0.640	0.572	1.193	1.056	0.923
	(27.33)	(26.32)	(9.40)	(11.96)	(19.67)	(14.72)	(9.85)
Second lag of R&D stock	-0.194	-0.153	0.298	0.428	-0.291	-0.034	0.228
	(3.30)	(2.37)	(4.48)	(5.48)	(3.99)	(0.32)	(1.08)
Second lag of Secondary school	0.076	0.486	0.031	0.039	0.322	0.161	0.366
	(0.32)	(1.73)	(0.24)	(0.42)	(0.66)	(0.32)	(1.26)
Expropriation risk Index	-0.511	-0.951	0.238	0.706	-2.021	-0.981	0.010
	(1.05)	(1.65)	(0.82)	(3.10)	(2.36)	(0.96)	(0.02)
Manufacturing import/trade	1.253	1.480	0.748	0.343	2.109	2.624	0.699
	(2.11)	(2.11)	(2.31)	(1.34)	(2.12)	(2.93)	(0.81)
U.S. trade/GDP	-0.073	-0.229	0.171	0.154	-0.178	-0.413	0.112
	(1.20)	(2.17)	(4.10)	(3.19)	(1.56)	(3.11)	(1.42)
Openness	0.079	0.464	-0.460	-0.133	0.800	0.438	0.272
	(0.49)	(3.15)	(6.74)	(2.05)	(3.64)	(2.26)	(1.23)
R squared	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Observations	285	210	75	135	120	135	120
Number of countries	19	14	5	9	8	9	8

Sources: R&D stock (OECD, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) employment (WEO, 2002), expropriation risk index (World Bank, International Country Risk Guide), import/trade (OECD, 2002), U.S. trade (IMF Direction of Trade Database).

Notes: Heteroskedasticity corrected z statistics are in parentheses. All variables are in natural logs and normalized by labor. All regressions include time dummies. Greece is not included in the analysis, as it does not have data on imports in manufacturing sector.

Table 13. Ordinary Least Square (OLS) Regression Analysis of per Labor GDP, 1981-97

	Full Sample	Non-OECD	OECD	Sub Samples of OECD Non-G-7-	G-7	Large Market	Small Market	High Income	Low Income
Initial GDP	0.705 (25.66)	0.408 (12.08)	0.597 (12.91)	0.620 (9.29)	0.695 (11.12)	0.479 (6.90)	0.752 (9.49)	0.784 (4.33)	0.869 (8.58)
Investment	0.295 (23.16)	0.482 (23.34)	0.254 (13.94)	0.243 (11.89)	0.215 (5.13)	0.276 (8.44)	0.223 (8.12)	0.204 (8.02)	0.239 (7.89)
Second lag of patent stock	0.022 (3.47)	0.075 (6.29)	0.020 (3.06)	0.009 (0.93)	0.002 (0.17)	0.013 (1.73)	0.008 (0.46)	0.021 (1.03)	0.013 (1.13)
Second lag of secondary school	-0.037 (1.41)	-0.003 (0.12)	-0.039 (1.48)	-0.046 (1.46)	-0.031 (0.88)	-0.015 (0.58)	0.008 (0.18)	-0.048 (1.06)	-0.010 (0.30)
Openness	0.018 (1.77)	-0.070 (5.26)	0.049 (3.12)	0.111 (4.77)	0.029 (1.19)	-0.011 (0.58)	0.060 (1.99)	0.039 (1.96)	0.114 (2.95)
Expropriation risk	-0.009 (0.52)	0.018 (0.65)	0.104 (2.94)	0.101 (2.70)	0.060 (0.60)	0.054 (0.90)	0.012 (0.27)	0.178 (2.11)	0.086 (2.43)
R-squared	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Observations	449	149	300	225	75	135	135	135	135
Number of countries	30	10	20	15	5	9	9	9	9

Sources: GDP, investment, secondary school enrolments (WDI, 2002), employment (WEO, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) expropriation risk index (World Bank, International Country Risk Guide).

Notes: z statistics in parentheses. GDP, investment and patents are normalized by employment series. All variables are in natural logarithm, and all regressions include time dummies.

II. Correlation Table and Summary Statistics

Table 14. Pairwise Correlation Table[1]

Full Sample	GDP	Investment	Patent stock	R&D stock	Secondary school	Openness	Expropriation risk	Import/ trade in manufacturing	US trade/ GDP
GDP	1								
Investment	0.97*	1							
Patent stock	0.92*	0.86*	1						
R&D stock	0.70*	0.55*	0.76*	1					
Secondary school	0.72*	0.70*	0.76*	0.34*	1				
Openness	0.17*	0.24*	0.14*	0.05	0.24*	1			
Expropriation risk	0.51*	0.58*	0.53*	0.29*	0.50*	0.26*	1		
Import/trade in manufacturing	0.26*	0.30*	0.22*	0.24*	-0.03	-0.35*	-0.06	1	
US trade/GDP	-0.18*	-0.14*	-0.10*	0.23*	-0.22*	0.64*	-0.04	0.06	1

OECD Sample	GDP	Investment	Patent stock	R&D stock	Secondary school	Openness	Expropriation risk	Import/ trade in manufacturing	US trade/ GDP
GDP	1								
Investment	0.88*	1							
Patent stock	0.81*	0.65*	1						
R&D Stock	0.70*	0.55*	0.76*	1					
Secondary school	0.57*	0.43*	0.45*	0.34*	1				
Openness	-0.01	-0.18*	-0.02	0.05	0.20*	1			
Expropriation risk	0.49*	0.41*	0.45*	0.29*	0.48*	0.08	1		
Import/trade in manufacturing	0.26*	0.30*	0.22*	0.24*	-0.03	-0.35*	-0.06	1	
US trade/GDP	0.01	-0.086	0.30*	0.23*	0.06	0.43*	0.09*	0.06	1

Non-OECD Sample	GDP	Investment	Patent stock	R&D stock	Secondary school	Openness	Expropriation risk	Import/ trade in manufacturing	US trade/ GDP
GDP	1								
Investment	0.97*	1							
Patent stock	0.92*	0.84*	1						
Secondary school	0.33*	0.37*	0.41*	--	1				
Openness	0.29*	0.44*	0.35*	--	0.40*	1			
Expropriation risk	0.17*	0.36*	0.16*	--	0.09	0.37*	1		
US trade/GDP	0.20*	0.30*	0.25*	--	0.13*	0.90*	0.23*	--	1

Sources: GDP, investment, secondary school enrolments (WDI, 2002), employment (WEO, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) expropriation risk index (World Bank, International Country Risk Guide), Imports /trade in manufacturing sector (OECD, 2002).

Note: (*) significant at 10 percent significance level.
1/ All variables are in natural logs. GDP, investment, patents and R&D stock are normalized by labor.

Table 15. Summary Statistics of the Variables

Full Sample	N	Min	Max	Mean	Median	Std Dev
GDP	523	505	83442	38018	40166	22330
Investment	509	251	24888	8085	7819	4985
Patents	523	0.01	429	69	39	88
R&D Expenditure	340	65.80	2780	776	700	485
Secondary school enrolments	523	21.81	157.09	85.19	90.91	27
Openness	509	12.87	427.95	76.67	57.61	71
Expropriation risk	523	3.25	11.00	8.74	9.00	1.65
US Trade/GDP	523	0.01	0.55	0.09	0.05	0.10

OECD	N	Min	Max	Mean	Median	Std Dev
GDP	340	17504	83442	50583	50576	15046
Investment	340	3249	24888	10084	9123	4015
Patents	340	0.2	430	103	80	92
R&D Expenditure	340	66	2780	777	701	485
Secondary school enrolments	340	41.20	157.09	100.44	99.15	17.37
Openness	340	15.92	146.95	64.84	62.09	27.66
Expropriation risk	340	4.25	10.00	9.38	10.00	1.00
Import/trade in manufacturing	323	0.45	0.61	0.51	0.50	0.02
US trade/GDP	340	0.01	0.52	0.06	0.04	0.07

Non-OECD	N	Min	Max	Mean	Median	Std Dev
GDP	183	505	52752	14674	10764	12868
Investment	169	251	20820	4063	2390	4272
Patents	183	0.01	71	6	1	12
Secondary school enrolments	183	21.81	97.64	56.86	58.95	17.08
Openness	169	12.87	427.95	100.45	49.90	112.45
Expropriation risk	183	3.25	11.00	7.55	8.00	1.93
US trade/GDP	183	0.02	0.55	0.13	0.08	0.13

Sources: GDP, investment, secondary school enrolments (WDI, 2002), employment (WEO, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) expropriation risk index (World Bank, International Country Risk Guide), import/trade in manufacturing sector (OECD, 2002).

Note: GDP and investment are in per labor. Patents and R&D stock are in per million-labor.

Table 16. Summary Statistics of the Growth Rates of the Variables

Full	N	Min	Max	Mean	Median	Std Dev
GDP	492	-0.134	0.122	0.017	0.018	0.036
Investment	479	-0.403	0.263	0.014	0.022	0.085
Patents	492	-1.584	1.792	0.040	0.031	0.357
R&D Expenditure	320	-0.962	0.558	0.024	0.022	0.145
Secondary school enrolment	492	-0.157	0.455	0.020	0.011	0.044
Openness	479	-0.425	0.361	0.008	0.010	0.076
Expropriation risk	493	-0.452	0.486	0.017	0.000	0.068
US trade/GDP	492	-0.576	0.549	0.003	0.001	0.147

OECD	N	Min	Max	Mean	Median	Std Dev
GDP	320	-0.100	0.122	0.015	0.016	0.026
Investment	320	-0.239	0.235	0.013	0.018	0.065
Patents	320	-1.584	1.792	0.023	0.022	0.307
R&D Expenditure	320	-0.962	0.558	0.024	0.022	0.145
Secondary school enrolment	320	-0.079	0.455	0.019	0.009	0.047
Openness	320	-0.303	0.146	0.006	0.007	0.059
Expropriation risk	321	-0.031	0.288	0.010	0.000	0.038
Import/trade in manufacturing	304	-0.109	0.132	-0.001	-0.001	0.021
US trade/GDP	320	-0.452	0.455	-0.002	0.004	0.142

Non-OECD	N	Min	Max	Mean	Median	Std Dev
GDP	172	-0.134	0.121	0.022	0.030	0.049
Investment	159	-0.403	0.263	0.018	0.046	0.116
Patents	172	-1.152	1.577	0.073	0.065	0.435
Secondary school enrolment	172	-0.157	0.135	0.023	0.014	0.036
Openness	159	-0.425	0.361	0.013	0.021	0.102
Expropriation risk	172	-0.452	0.486	0.030	0.000	0.101
US trade/GDP	172	-0.576	0.549	0.010	-0.001	0.155

Sources: GDP, investment, secondary school enrolments (WDI, 2002), employment (WEO, 2002), patent applications (NBER Patent Citation Database), openness (PWT 6) expropriation risk index (World Bank, International Country Risk Guide), import/trade in manufacturing sector (OECD, 2002).

Note: All variables are log differenced. GDP and investment are in per labor. Patents and R&D stock are in per million-labor.

Table 17. Country Codes

AU: Australia	DK: Denmark	GR: Greece	NL: Netherlands
AT: Austria	ES: Spain	IE: Ireland	NO: Norway
BE: Belgium	FI: Finland	IS: Iceland	NZ: New Zealand
CA: Canada	FR: France	IT: Italy	PT: Portugal
CH: Switzerland	GB: Great Britain	JP: Japan	SE: Sweden

References

Aghion, Philippe, and Peter Howitt, 1998, "Endogenous Growth Theory," (Cambridge, Massachusetts: The MIT Press).

Arellano, Manuel, and Stephen Bond, 1991, "Some Tests for Specification of Panel Data," *Review of Economic Studies*, Vol. 58, pp. 277–97.

Arrow, Kenneth J., 1962, "The Economic Implications of Learning by Doing," *Review of Economic Studies*, Vol. 29, No. 3, pp. 155-73.

Acemoglu, Daron, Joshua Linn, 2003, "Market Size and Innovation: Theory and Evidence from the Pharmaceutical Industry," NBER Working Paper 10038, (Cambridge, Massachusetts: National Bureau of Economic Research).

Coe, David T., Elhanan Helpman, and Alexander W. Hoffmaister, 1995, "North-South R&D Spillovers," NBER Working Paper, No. 5048, (Cambridge, Massachusetts: National Bureau of Economic Research).

Comanor, William S., F.M. Scherer, 1969, "Patent Statistics as a Measure of Technical Change," *Journal of Political Economy*, Vol 77, pp. 392-98.

Frantzen, Dirk, 2000, "R&D, Human Capital and International Technology Spillovers: A Cross Country Analysis," *Scandinavian Journal of Economics*, Vol. 102 No. 1, pp. 57-75.

Griffith Rachel, Stephen Redding, and John Van Reenen, 2001, "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Countries," The Institute for Fiscal Studies, Working Paper, 02/00 (London, United Kingdom: The Institute for Fiscal Studies).

Griliches, Zvi, 1957, "Hybrid Corn: An Exploration in the Economics of Technological Change," *Econometrica*, No. 25, pp. 501-22.

Griliches, Zvi, Jacob Schmookler, 1963, "Inventing and Maximizing," *The American Economic Review*, Vol. 53 No. 4, pp. 725-29.

Griliches, Zvi, 1981, "Market Value, R&D and Patents," Economics Letters Vol 7, pp. l8387.

Griliches, Zvi, Frank Lichtenberg, 1984, "Interindustry Technology Flows and Productivity Growth: A Reexamination," *Review of Economics and Statistics*, Vol. 66, pp. 324–29.

Griliches, Zvi, 1986, “Productivity, R&D and Basic Research at the Firm Level in the 1970s,” *American Economic Review,* Vol. 76, pp. 141–54.

———, 1990, “Patent Statistics as Economic Indicators: A survey,” *Journal of Economic Literature,* Vol. xxviii, pp. 1661-1707.

———, 1994, “Productivity, R&D, and the Data Constraint,” *American Economic Review,* Vol. 84, pp. 9–21.

Hall, Bronwyn H., Zvi Griliches, and Jerry A. Hausman, 1986, “Patents and R&D: Is There a Lag?” *International Economic Review*, Vol.27, pp.165–283.

Hall, Bronwyn H., Adam Jaffe, and Manuel Trajtenberg, 2001, “The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools,” NBER Working Paper 8498, (Cambridge, Massachusetts: National Bureau of Economic Research).

———, 2002, “Market Value and Patent Citations: A First Look,” Development and Comp Systems, Economics Working Paper Archive.

Islam, Nazrul, 1995, “Growth Empirics: A Panel Data Approach,” *Quarterly Journal of Economics,* Vol. CX No. 4, pp. 1127-70.

Jaffe, Adam B., 1986, “Technological Opportunity and Spillovers of R&D: Evidence from Firms’ Patents, Profits and Market Value,” *American Economic Review*, Vol. 76, pp. 984–1001.

———, 1989, “Real Effects of Academic Research,” *American Economic Review*, Vol. 79, pp. 957–70.

Jones, Charles I., 1995b, “Time Series Test of Endogenous Growth Models,” *Quarterly Journal of Economics*, pp. 495–525.

Levin, A., C. Lin, and J. Chu, 2002, “Unit Root Tests in Panel Data: Asymptotic and Finite-Sample Properties,” *Journal of Econometrics*, Vol. 108, No. 1, pp. 1–24.

Lucas, R.E. Jr., 1988, “On the Mechanics of Economic Development,” *Journal of Monetary Economics,* Vol. 22, No.1, pp.3–42.

Pakes, Ariel, 1985, “On Patents, R&D, and the Stock Market Rate of Return,” *Journal of Political Economy*, Vol.93, pp. 390–409.

Porter, Michael E., and Scott Stern, 2000, “Measuring the ‘Ideas’ Production Function: Evidence from International Patent Output,” NBER Working Paper No. 7891, (Cambridge: Massachusetts: National Bureau of Economic Research).

Romer, Paul M., 1986, "Increasing Returns and Long Run Growth," *Journal of Political Economy,* Vol. 94, pp.1002–37.

———, 1990, "Endogenous Technical Change," *Journal of Political Economy*, Vol. 98, pp. 71–102.

———, 1994, "The Origins of Endogenous Growth," *Journal of Economic Perspectives*, Vol. 8, pp. 3–22.

Rouvinen, Petri, 1999, "Issues in R&D-Productivity Dynamics: Causality, Lags, and Dry Holes," (Helsinki, Finland: The Research Institute of Finnish Economy).

Savvides, Andreas, Marios Zachariadis, 2003, "International Technology Diffusion and TFP Growth," (forthcoming, Oklahoma: Oklahoma State University, Department of Economics).

Schmookler, Jacob and Oswald Brownlee, 1962, "Determinants of Inventive Activity," *The American Economic Review*, Vol. 52, No. 2, pp. 165-76.

Scherer, F.M., 1982 "Inter-Industry Technology Flows and Productivity Growth," *The Review of Economics and Statistics*, Vol. 64, pp. 627-34

Zachariadis, Marios, 2003 "R&D, Innovation, and Technological Progress: A test of the Schumpeterian Framework without Scale Effects," *Canadian Journal of Economics*, Vol 36, No. 3, pp. 566-686.