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

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Abstract: This paper investigates the relationship between R&D, invention and economic growth using international panel data of R&D expenditure and patent applications from 20 OECD countries for the period of 1981 and 1997. Our analysis suggests that though only countries with larger markets can increase their invention by investing in R&D, in most countries invention has a positive effect on per capita income growth. According to our analysis, higher income countries with larger markets receive the highest returns to their invention in terms of per capita output, and higher income countries with smaller markets receive the lowest returns. The fact that the effect of invention on per capita output is the largest in higher income countries implies that rich countries are not constrained by stagnant output growth, as implied by exogenous growth models. These results support endogenous growth theories which predict that countries' R&D efforts may foster economic growth.

1. Introduction

Since its introduction in 1956 a vast amount of work has been devoted until the late 1980'ies to the empirical analysis of Solow model. However, despite the three decades of research, the convergence implication of Solow model was not confirmed by data, that is poor countries were not catching up with the rich ones. This raised the question about the validity of one of the central assumptions of the model, namely technology is exogenous. Romer (1986) and Lucas (1988) endogenized technology and provided more satisfactory explanations about the patterns of the growth rates of world economies. The main premises of these endogenous growth theories are that technology--invention--is created by the R&D efforts of firms and by externalities stemming from capital accumulation. Contrary to the Solow model, endogenous growth theories recognize that countries can determine their own technology level and attain perpetual economic growth by investing in technology. From this it follows that the growth rates of countries do not necessarily converge over time.

Although endogenous growth theories have started a new era in the growth literature, their strength has been undermined by difficulties in testing their implications, due to mainly constraints in obtaining data on invention and R&D investment. To overcome this problem, this paper attempts to evaluate the relationship between R&D investment, invention and output using R&D expenditure as a proxy for R&D investment, and patent applications as a proxy for invention from 20 OECD countries for the period of 1981-1997.

The findings of this analysis suggest that only countries with larger markets are able to increase their invention by investing in R&D. Moreover, the positive effects of invention on economic growth have been observed in most of the countries regardless of their income level and market size. This paper is one of the first, exploring the relationship between R&D, invention and economic growth using international panel data of patent and R&D expenditure.

The remaining part of the paper is organized as follows: the subsequent section reviews the growth literature, section three presents the model, section four describes the data, section five reports the results of the empirical analysis and section six concludes.

2. Literature Survey of Growth Models

The main implication of exogenous growth models is that the per capita growth rate of output across countries converges over time. This result is obtained because countries with low per capita income grow faster than countries with high per capita income. This convergence follows directly from the two assumptions of these models: technological change is exogenous and constant across countries.

The implication that per capita growth rate of output converges over time has been tested in several studies. William Baumol (1986) found that the gap between per capita growth rates of poor and rich countries closes by the end of the period from 1870-1979. However, his results have been criticized by other studies: First, Abramowitz (1986) used the same data set and found that convergence does not occur for the whole period but only from 1950 to 1979. Second, De Long (1988) pointed out that developed countries in Baumol's paper are determined ex-post, which accounts for most of the convergence across countries. Romer (1994) used a larger data set and found no indication of convergence across countries.

These findings against the convergence implication of neo classical economic theories raised the question of why poor countries are not catching up with the rich ones? This question motivated new growth theories pioneered by Romer (1986) and Lucas (1988). These theories eliminate two central assumptions of neo classical models: first, technological change is exogenous; second, technology is the same across countries. Once technology is endogenized, the answer to the question above is straightforward: poor countries are not catching up with rich countries because production function no longer exhibits diminishing returns to scale. In other words, when technology is allowed to change across countries, countries with low capital stock do not necessarily grow faster than the countries with high capital stock, as the latter can increase their growth rate further by investing in technology.

Although there are many different models of endogenous growth, they can be examined in two main categories, namely, spillover models and R&D models. Spillover models, pioneered by Arrow (1962), Romer (1986) and Lucas (1988) assert that technology is created in an economy as a result of externalities stemming from private research activities and human capital accumulation[1]. By assuming that technology is just a by-product of human capital accumulation and the research activities of firms, these models try to endogenize technology and at the same time avoid the theoretical complications of the imperfect competition, which could arise if technology was created by the profit motivated firms. In these models, production functions are assumed to exhibit constant returns to scale with respect to inputs, just like exogenous growth models. They differ from exogenous growth models in that they explain permanent increases in the growth rate of an economy as a result of endogenous increases in technology. These models are very helpful to understand how sustainable growth can be attained. However, they are not complete as they ignore the R&D efforts of firms that are directly channeled to produce new ideas and are motivated by profit.

The R&D based models, pioneered by Romer (1987b, 1990), and Grossman and Helpman (1994) goes one step further by incorporating imperfect competition into growth models.[2] These models are based on three sectors: the final output sector, the intermediate goods sector and the R&D sector. The R&D sector uses human capital to produce new ideas and designs. After creating these ideas it then sells them to the intermediate goods sector. The intermediate goods sector patents these new ideas and gets monopoly rights to exclusively produce the new products designed by these ideas. It then sells these intermediate goods to the final output sector. The R&D sector is the key sector in these models for sustainable growth.

Generally, empirical studies of these models involve testing the effect of R&D variables on total factor productivity growth. Jones (1995) examines the R&D based growth models using simple time series plots of the growth rate of the number of engineers and scientists against total factor productivity growth for France, Germany, Japan and the United States. He finds no evidence of any increase in total factor productivity growth in spite of a continuous increase in the growth rate of the number of engineers and scientists. He argues that this

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[1]The production function in Romer (1986) is: $Y=A(R)F(R_j, K_j, L_j)$ where Rj stands for R&D investment by firm j. In this model the source of spillovers is R&D efforts of the firms. Lucas (1988) uses the production function: Y=A(H)F(Hj, Kj) where Hj stands for human capital, which is the source of spillovers in his model. In both models, production function of the firms exhibits CRS in all inputs. However, the technology coefficient A has the coefficient of one and increases through time as a result of the spillovers from R&D investment (Rj) and human capital (Hj), leading to continuous increases in the growth rate of output.

[2] These models are also called neo-Shumpeterian models as the idea of monopolistic competition in growth models was suggested first by Shumpeter (1942).

result is evidence of decreasing returns to production of new knowledge: more knowledge has already been accumulated therefore it is harder to extend it.

Aghon and Howit (1998) provide reasons for the observation that an increase in the growth rate of the number of engineers and scientists did not lead to a corresponding increase in productivity growth. First, the increasing complexity of technology makes it necessary to raise R&D over time just to keep the invention rate constant for each product. Second, as the number of products increases, an invention in any one product directly affects a smaller proportion of the economy, and therefore, has a smaller proportional spillover effect on the aggregate stock of knowledge.

Aghon and Howit (1998) also argue that instead of using the number of engineers and scientists engaged in the R&D sectors, the fraction of GDP allocated to R&D should be used to test the implication of R&D based models. Simply counting the number of engineers and scientist fails to take into account the size of the economy. They test the implication of R&D based models using data on R&D expenditures for the U.S as a fraction of GDP, and find that there is no tendency for that fraction to rise. They conclude that U.S R&D confirms endogenous growth theory rather than contradicting it.

Coe, Helpman and Hoffmaister (1995) use a multicountry model to examine the effects of R&D spillovers from industrialized countries to developing countries on total factor productivity growth in the latter. They use data for 77 developing countries over the period of 1971-1990 and find that there are substantial R&D spillovers from developed to developing countries. These spillovers have a positive and significant effect on total factor productivity of developing countries.

In addition to the macro level empirical studies presented above, there are firm-level empirical studies that examine the effect of R&D efforts on productivity growth. Zvi Griliches, Ariele Pakes, Brownyn Hall, Frank Lichtenberg and Adam Jaffe are the main contributors to this research. Griliches (1986) uses R&D data obtained from the National Science Foundation to investigate the relationship between R&D efforts and productivity growth in U.S. manufacturing firms. He finds a positive relationship between R&D efforts and productivity growth.

Jaffe (1988) uses firm level patent data and R&D data from the U.S manufacturing sector to find the effect of firms' own R&D efforts, and spillovers stemming from other firms'

R&D efforts on the productivity growth of the firms. He finds that both factors have a positive effect on productivity growth.

The brief survey of the growth literature documented above indicates that the implications of endogenous growth theories are not only theoretical but are observable in modern economics. Making use of available data, these studies are able to answer the fundamental questions that neo-classical studies could not. As more studies are conducted and more data become available, endogenous growth theories will be able to answer more questions about the nature of economic growth and technological change.

3. The Model

3.1. Description of the Model

The R&D based growth model in Romer (1990b) assumes that there are three sectors-- R&D, intermediate and final goods sector-- and four goods in the economy--capital, labor, human capital and an index of the level of technology. The research sector uses human capital and the existing stock of knowledge to produce designs for new producer durables. An intermediate-goods sector uses these designs from the research sector together with forgone output to produce the large number of producer durables that are available for use in final goods production at any time. The final goods sector uses labor, human capital and the set of producer durables that are available to produce final output. Output can be either consumed or saved as new capital. The simplifying assumptions of the model are: 1. population and the supply of labor are both constant, 2. the stock of human capital in the populaiton and the fraction of it supplied to market is fixed, 3. the research sector uses only human capital and the existing knowledge stock. The second assumption together with the first assumption implies constant supply of labor and human capital which simplifies the dynamic solution of the model. In the third assumption labor and capital do not enter into production of new ideas at all. The functional form for final output can be written as follows

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

Unlike conventional Cobb-Douglas function, this production function specifies output as an additively separable function of all different types of capital and durable goods, so that a one-dollar increase in one of them will have no effect on the marginal product of the others. As the production function exhibits constant returns to scale in all of its inputs, the final output sector can be represented by a single, aggregate, price-taking firm.

In the durable goods sector there is a distinct firm i for each durable good i. A firm must purchase or produce a design for good i before production. Once it owns the design, the firm can convert η units of final output into one unit of durable good i. A firm that produces a design for durable i can obtain an infinitely lived patent on that design. If the firm manufactures $x(i)$ units of the durable goods, it rents those durables to final-output firms for a rental rate $p(i)$. Since firm i will be the only seller of capital good i, it will face a downward-sloping demand curve for its good. The value of one unit of durable i is the present discounted value of the infinite stream of rental income that it generates. Total capital evolves according to the following equation

$$\dot{K}(t) = Y(t) - C(t). \qquad (2)$$

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

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

Research output depends on the amount of human capital devoted to research, and on the stock of knowledge available to a person doing research. If the researcher possesses an amount of human capital (H_j) and has an access to a portion A_j of the total stock of knowledge implicit in previous designs, the rate of production of new designs by researcher j will be $\delta H_j A_j$, where δ is a productivity parameter. The equilibrium in this model is based on the assumption that anyone engaged in research has free access to the entire stock of knowledge. This is feasible because knowledge is a non-rival input. The aggregate stock of designs therefore evolves according to the following equation:

$$\dot{A} = \delta H_A A \qquad (3)$$

where H_A is the total human capital employed in research. This equation is the heart of this model. The crucial property of this equation that leads to perpetual growth of output is that the growth rate of technology is linear in both H_A and A, when one is held constant. This has two implications: First, devoting more human capital to research leads to a higher rate of production of new designs; and 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. New designs enter 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 thereby increases the productivity of human capital in the research sector.

The representative final output firm chooses a profit maximizing quantity $x(i)$ for each durable good according to the following equation:

$$Max_x = \int_0^\infty [H_Y^\alpha L^\beta x(i)^{1-\alpha-\beta} - p(i)x(i)]d_i.$$

Differentiation of the above equation with respect to $x(i)$ yields an inverse demand curve for intermediate good $x(i)$:

$$p(i) = (1-\alpha-\beta)H_Y^\alpha L^\beta x(i)^{-\alpha-\beta}. \qquad (4)$$

Producers in the intermediate goods sector take this demand curve as given when they produce durable goods. Thus, the profit maximizing level of output of the intermediate goods sector is:

$$\Pi = \max_x p(x)x - r\eta x$$
$$= \max_x (1-\alpha-\beta)H_Y^{\alpha} L^{\beta} x^{-\alpha-\beta} - r\eta x \qquad (5)$$

where $p(x)$ times x is the flow of rental income from renting intermediate goods to the final goods sector, $r\eta x$ is the total cost due to forgone interest income on η units of output to produce x durables. The resulting monopoly price is a simple markup over
marginal cost, where the markup is determined by the elasticity of demand, $p = r\eta/(1-\alpha-\beta)$. The flow of monopoly profit is $\Pi = (\alpha+\beta)px$, where x is the quantity in equation (4) implied by price p. Firms cannot price discriminate so they have to charge a single monopoly price for their durables rented to the final goods sector.

Because the market for designs is competitive, the price of designs will be bid up until it is equal to the present value of the net revenue that a monopolist can extract. At every date t, it must therefore be true that

$$\int_t^{\infty} e^{\int_t^{\infty} r(s)ds} \pi(\tau)d\tau = P_A(t) \qquad (6)$$

where P_A is the price of new designs. Differentiating the above equation with respect to time and substituting that back into equation 6, with the assumption that P_A is constant, yields $\Pi(t) = r(t)P_A$. This equation says that at every point in time, the instantaneous excess of revenue over marginal cost must be just sufficient to cover the interest cost on the initial investment in a design.

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

$$Y(H_A, L, x) = (H_Y A)^{\alpha} (LA)^{\beta} (K)^{1-\alpha-\beta} \eta^{\alpha+\beta-1}. \qquad (7)$$

Increasing returns to scale (non-convexity) arises in both R&D and final output sectors because both sectors use non-rival good A as an input. A enters into the R&D sector directly and into the final good production process indirectly through knowledge spillovers.

Equation (7) implies that if A grows at an exogenously determined exponential rate, the economy would converge to a path on which K grows at the rate of A, as it does in the Solow model. During the transition period the ratio of K to A would change, which implies that r and x would change as well. Along the balanced growth path, r, x and the ratio of K to A are all constant. Romer (1990) solves this model at the balanced growth path, similar to the Solow model, where all *K, C, L* and A grow at a constant rate. The solution of the model yield the balanced growth rate of the variables shown in equation 8

$$g = \frac{\dot{C}}{C} = \frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{A}}{A} \quad \delta H_A. \qquad (8)$$

Implicitly, the allocation of H between the two sectors is constrained by the requirement that H_A must be nonnegative and H_Y can be no larger than H. This implies that g is nonnegative. The relation between the growth rate g and the interest rate r implied by

$$g = \frac{\dot{C}}{C} = \frac{r - \rho}{\sigma}. \qquad (9)$$

Combined with equation (8), this gives an expression for g in terms of the fundamentals of the model

$$g = \frac{\delta H - \Lambda\rho}{\sigma\Lambda + 1}. \qquad (10)$$

where

$$\Lambda = \frac{\alpha}{(-\alpha - \beta)(\alpha + \beta)}$$

For the integral representing consumer's preferences to be finite, the rate of growth of current utility $(1-\sigma)g$ must be less than the discount rate ρ .[3]

3.2. Implications of the Model

Equation (8) summarizes the effects of the technological side of the model, including the effects of imperfect competition in the market for producer durables. One interpretation of equation (8) is that as r increases, the present discounted value of the stream of net revenue will be lower in the R&D sector, therefore, less human capital will be allocated to research, and the rate of growth will be lower. From equation (9) it follows that any change in the preference parameters that acts to reduce the interest rate will increase research and growth. This implication follows directly from the assumption that the benefits of research come largely in the future while the costs are incurred immediately.

There are two reasons why too little human capital is devoted to the research sector. First, research has external effects. An additional design raises the productivity of all future individuals who will do research, but because this benefit is non-excludable, it is not reflected at all in the market price for the designs. Second, research produces an input that is purchased by a sector that engages in monopoly pricing, which creates a wedge between the marginal product of an input used in this sector and its market compensation.

As seen from equation (8), an increase in human capital increases the growth rate. Human capital in this model serves as a scale variable because it is the input that is used most intensively in the research sector. This model implies that a subsidy to the research sector that is financed by lump-sum taxes will increase the growth rate of output because it has the same effect as an increase in the productivity parameter δ in equation (2).

[3] For technical details of the derivation of the model see Romer (1990).

4. Description of Data and Methodology

Three different data sets are used in this paper: Patent data, R&D data and data on other macroeconomic variables. Patent data is obtained from the U.S. Patent Office. It includes utility patents in the manufacturing sector applied by the inventors of different countries during the period of 1981-1997. Utility patents are classified according to five main categories: chemical, computers and communication, drugs and medical, electrical and electronic and others. 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 counts for each country are constructed by counting all the utility patent applications according to the inventors' countries. The patent stock is calculated using 0.20 percent depreciation rate as suggested in the literature.[4]

Gross R&D expenditure (GERD) data is obtained from the OECD Main Statistics and Technology Indicators database. GERD is defined as total intramural expenditure on R&D performed on national territory during a given period. It includes R&D performed within a country and funded from abroad but excludes payments made abroad for R&D. GERD is constructed by adding together the intramural expenditures of the four performing sectors: Business enterprises, government sector, higher education and non-profit firms. R&D series are deflated using the 1995 implicit price deflator and converted to $US using the monthly averages of the exchange rates obtained from the OECD database. The main shortcoming of the R&D data set is that most of the member countries have data for every other year. The gaps between two years are filled using averages of preceding and succeeding years.

The remaining macroeconomic variables are obtained from the following databases: GDP, gross fixed investment, secondary school enrollments, import and export data for manufacturing goods (WDI 2002); employment and population (OECD); total imports and exports of goods and services and GDP in current prices (WEO 2002); corruption index and expropriation risk index (World Bank, International Country Risk Guide) and the US trade

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[4] The formula used to calculate the 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 patent stock. The patent stock for subsequent years is calculated using the formula $Ps_t = P_t + (1-\delta)Ps_{t-1}$.

share (IMF Direction of Trade Database (IMFDOT). All variables except for the variables that are the share of GDP, patent counts and the indices are in constant 1995 $US.

The corruption index ranges from 1 to 6, which takes higher values for lower level of corruption. The risk of expropriation index ranges from 1 to 10, which takes high values for low level of risk of expropriation.

The openness variable is constructed by adding total exports and imports of countries in goods and services and dividing that amount by aggregate GDP. Similarly, trade share of US is calculated adding the total exports and imports of US for each partner country and normalizing this total by each countries' 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.

Total factor productivity (TFP) growth is calculated using the growth accounting method. In particular, after taking into account the contribution of investment and labor to the growth rate of output, the residual is computed as total factor productivity growth. Because wage data and interest rate data are not available for long periods, labor share and investment share are set to 0.6 and 0.4 respectively, as suggested in the literature.

5. Empirical Analysis

The relationship between R&D, invention and economic growth has been analyzed using patent applications from the U.S. Patent Office as a proxy for invention, and the R&D expenditures from OECD database as a proxy for R&D efforts of countries. The data include 20 OECD countries having complete data for the period of 1981-1997[5]. If the implications of R&D based growth models hold, we should obtain a positive and significant relationship between R&D investment and invention; and between invention and aggregate output.

The estimation of both invention and aggregate output has been conducted with three different panel data regression techniques: ordinary least squares (OLS), fixed effects and

[5] These countries are Austria, Australia, Belgium, Canada, Finland, France, Greece, Switzerland, Denmark, Spain, UK, Ireland, Iceland, Italy, Japan, Netherlands, Norway, New Zealand, Portugal, and Sweden. USA is not included in regression analysis as the patent data is obtained from the U.S. Patent Office. Czech Republic and Germany did not have the R&D data, and Turkey, Mexico, Korea, Hungary and Poland had only 5 year data at most.

Arellano-Bond GMM estimator of dynamic panel data. Each of these analyses has its own merits. In particular, the pooled OLS panel data estimator enables us to use the information from both time series and cross sectional dimension of data. However, in the presence of country specific factors and endogeneity problem, the OLS estimators are biased as the regressors are correlated with the error term. When country specific factors are present, the fixed effects regression analysis yields consistent estimators. Nevertheless, if the lagged dependent variable is included in the model to account for endogeneity between variables, the coefficients obtained from the fixed effects analysis are no longer consistent. The GMM estimator takes into account both country fixed effects and the endogeneity problem by using the first differences of the variables and including the lagged dependent variable as an instrument in the analysis.[6] In addition, the endogeneity problem is further mitigated by using the second lags of R&D and patent series throughout the analysis. The first order autocorrelation problem which is present in the logged data has been accounted for either by using Cochrane-Orcutt transformation method or using the first differenced data. Moreover, the time dummies have been included in all regressions to take in to account time specific factors.

The remaining part of this section organized as follows: the next part presents some stylized facts and statistical analysis of the data regarding the main variables of the model, the following part estimates invention in terms of R&D investment, and the final part estimates the production function in terms of invention.

5.1. Analysis of Data

This section examines the cross sectional and time series characteristics of the main variables. The first cross sectional analysis has been carried out by ranking the countries according to their average levels of GDP, investment, R&D expenditure and patent applications. After the countries are ranked according to the above variables, they are then divided in two groups: the first 10 countries ranking highest in each variable are called high

[6] The paper uses Arellano-Bond Linear GMM Estimator embodied in STATA program. For technical details of this estimator see Arellano & Bond (1991).

ranking groups of that variable, and the last 10 countries have been called the low ranking groups. Table 1 presents these rankings. As seen from the table, countries with high GDP also have high investment with the only exception of Belgium and Austria, which are the two median countries. Among these countries, Iceland, Ireland, New Zealand, Portugal and Greece are in the lowest ranking, while Japan and Switzerland are in the highest ranking of both GDP and investment. The last two columns report the rankings of countries for R&D expenditure and patent applications. As seen from the table, the countries ranking high in R&D expenditure also rank high in patent applications with the exception of Belgium and Spain. In addition, out of 9 countries having both high levels of GDP and investment, 8 of them also have high R&D investment and patent applications. Furthermore, Japan and France rank the highest in all four variables with the exact ranking; and Greece, Portugal, Ireland, New Zealand and Iceland rank the lowest in all four variables.

To take into account the size of the economy, the rankings have also been made in terms of per capita averages of the above variables. The results are reported in Table 2. Similar to the previous results, the countries with high per capita GDP also have high per capita investment with the only exception of Belgium and Netherlands. Of these countries, 8 of them rank the same in both variables. Among these countries, Japan and Switzerland have the highest, while Portugal, Greece, Spain and Ireland have the lowest per capita income and investment. Furthermore, as seen from the last two columns of Table 2, the countries with high per capita R&D also have the high per capita patent applications, with only four exceptions: Canada, Austria, Norway and Iceland. Out of these countries, 6 of them have the same ranking in both variables, and four of these countries, namely Portugal, Greece, Spain and Ireland, fall in to the lowest ranking in both per capita R&D and patent applications.

Moreover, the comparison of Table 1 and 2 shows that France, Switzerland and Japan are always in the high ranking groups, while Portugal, Greece and Ireland are always in the low ranking group of both aggregate and per capita levels of all four variables mentioned above. These rankings indicate that, on average a country doing better in one of the four variables also does better in other three. This can also be observed from the correlation coefficients of the above variables reported in Table 3. In addition, the scatter plots of average per capita patent and R&D expenditure; and per capita GDP and per capita patents are presented in

Figures 1 and 2. As seen from these figures, these variables are positively correlated across countries.

The time series analyses of the variables have been conducted plotting the variables over time for each country. As seen from Figures 3 and 4, both patent flows and R&D; and GDP and patent flows move closely over time in most of the countries. In addition, as seen from Figure 5, which presents the total patent, R&D and GDP levels of all 20 OECD countries for each year, total patents and R&D expenditure reach their peak levels in 1995 and for the whole period they move very closely, while total GDP of these countries steadily increase over time.

In conclusion, both the cross sectional and time series analyses of R&D, patents and GDP show that these variables exhibit the patterns that are consistent with the prediction of endogenous growth models, in that they are positively associated. The following section provides more rigorous analysis of the relationship between R&D, invention and economic growth.

5.2. Estimation of Invention in terms of R&D Expenditure

The major contribution of endogenous growth theories to growth literature is that they can explain the determinants of technology, instead of simply assuming that it is exogenous and same across countries. The direct implication of these models is that, countries can attain sustainable economic growth by investing in R&D sectors and developing new and more efficient ways of producing output. This section tests this implication by examining whether countries can increase their invention level by investing in R&D sectors.

The analysis uses six different samples with different per capita incomes and market sizes. The main reason of using these samples is the presumption that R&D intensity might change across countries with different income levels and market sizes. This can easily be seen from the two main features of an R&D activity: first, R&D activities involve long term investments and high amount of uncertainty; second, the demand/market size plays an important role in determining these activities, as it increases the expected returns to invention. The first feature of R&D investment implies that countries should have certain levels of per capita income to invest in such a costly and long lasting activity; and the second feature implies that the countries with larger markets should have higher levels of invention for a given R&D expenditure, as they provide better incentives for the inventors. As a result, the effectiveness of R&D might differ across countries having different per capita incomes and market sizes.

As explained in details in the previous section these samples are constructed by ranking countries according to their aggregate and per capita GDP levels. In particular, the countries having higher level of aggregate GDP have been called as “larger market” countries, while the countries with lower level of aggregate GDP have been called as “smaller market” countries. Similarly, countries with higher per capita GDP have been called as “higher income”, while countries with lower per capita income level have been called as “lower income” countries.[7] To separate the effect of the market size from the effect of income level on invention, each sample has been constructed in isolation of each other. Detailed information about each sample is shown below:

1. Full sample. It includes all 20 OECD countries in the data
2. Larger market & lower income countries: These countries have higher aggregate GDP, but lower per capita GDP. United Kingdom, Italy, Canada, Spain, Netherlands and Australia fall in this group. This sample will enable us to separate the effect of large market from the effect of high income on invention.
3. Higher income & smaller market countries: This sample includes countries with higher per capita GDP, but lower aggregate GDP. These countries are Austria, Sweden, Norway, Finland, Denmark and Iceland. This sample enables us to isolate the effect of high income from the effect of large market on invention.
4. Higher income & larger market countries: These countries are in the high ranking group of both aggregate and per capita GDP. Japan, France, Switzerland and Belgium belong to this group.
5. Lower income & smaller market countries: They are in both low aggregate and per capita income group. These countries are New Zealand, Ireland, Greece, and Portugal.

[7] It should be kept in mind that all countries in the rankings are developed countries, most of which have very high levels of per capita GDP compared to the rest of the world. Therefore, the term “lower income countries” is valid only in comparison with the 20 OECD countries in the full sample.

6. Less advanced countries: This sample excludes the five top ranking countries in aggregate and per capita GDP from the full sample. The purpose of using this sample is to explore the relationship between R&D, invention and economic growth in countries with medium and lower level of income and market size.

The regression equation used in the analysis of R&D and invention is derived from equation (3) in section 2

$$\dot{A} = AH^{\theta} \qquad (3')$$

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

$$Log(\dot{A}) = Log(A) + \theta\, Log(H)\ . \qquad (3'')$$

Equation (3'') tells us that a one percent increase in human capital in the R&D sector increases the invention by θ percent, and a one percent increase in the knowledge stock (A) increases the invention by one percent. In the empirical analysis of the above equation the stock of R&D expenditure has been used for the human capital (H) in the R&D sectors, and the patent flows in manufacturing sector used for the flows of invention. The effect of the stock of invention (A) on invention flows has been taken into account in all regression analysis using various techniques.

In addition to the main variables mentioned above, the other variables included in the analysis are secondary school enrollments, corruption index, import export ratio of the countries in manufacturing goods, and the US trade share of GDP of each country. The secondary school enrollments and corruption index are used to capture the overall human capital and the legal environment of an economy, respectively. The import export ratio of the countries in the manufacturing sector is included to capture the technology spillovers across countries, i.e. the countries importing more manufacturing goods are be able to learn more about the know-how of the countries with high technological ability. The US trade share of GDP is included to control for the effect of economic alliance with US on the patent applications made in the U.S. Patent Office

The results of pooled OLS regression analysis are reported in Table 5. As observed from the table, the coefficient on R&D expenditure is positive and significant only in larger market countries regardless of their income levels, which imply the importance of the market size in the effectiveness of R&D investment in terms of invention. While most of the other samples do not have any significant returns to their R&D, the smaller market countries with lower per capita income have negative coefficient on R&D. However, these results should be taken cautiously as the OLS yields biased estimators in the presence of country fixed effects and endogeneity problem. In fact, it is these factors that caused negative and significant coefficient on R&D in the sample mentioned above.

Table 6 reports the results of fixed effects regression analysis, which yields unbiased estimators in the presence of country fixed effects. As Table 6 shows, returns to R&D are significant only in the larger market countries with lower per capita income. According to these results, a one percent increase in R&D investment is associated with a 0.17 percent increase in patent (invention) flows in larger market countries with lower per capita income. In addition, while corruption index and trade share of US are significant only in the larger market countries with lower income; the import export ratio is significant in the full sample, higher income countries with smaller market, and in the less advanced countries. One interesting observation from table 6 is that all of the countries that do not have significant returns to their R&D do have significant coefficient on import export ratio of manufacturing goods. This might imply that these countries import the know-how of other countries and use them to create their own invention, instead of investing in a formal R&D sector.

To check the robustness of the fixed effects results the Arellano-Bond GMM estimation has been employed as well. The results are reported in Table 7. As seen from the table, similar to the fixed effects regression results, the R&D coefficient is significant only in the larger market countries with lower per capita income, with a magnitude of 0.16. While the coefficient of import export ratio has expected sign and high t value in all samples, it is statistically significant only in the full sample and the less advanced countries. This again might be an indicator of technology spillovers across countries. The rest of the control variables are not significant in most of the samples.

The first conclusion from the above results is that R&D intensity changes across countries.[8] In addition, among the 6 samples used in the analysis, the larger market countries with lower income level are the only countries having significant returns to their invention. This implies that the market/demand size of countries is important determinant of the effectiveness of R&D investment. For sensitivity analysis the above regressions are repeated with larger groups of countries, i.e. all large market countries are included in the same sample regardless of their income levels, and all rich countries are included in the same group regardless of their market size. As seen from Table 1A in the appendix, the large market countries are still the only countries with significant returns to their R&D investment.

Furthermore, the results of the simple causality test reported in Table 2A, suggest that R&D investment is an important determinant of per capita patents. While this test does not imply a strict causality from R&D to per capita patents, it provides some understanding about the relationship between these two variables.

5.3. Estimation of Production Function in terms of Invention

This section explores the relationship between invention (patent stocks) and per capita GDP using slightly modified version of Cobb-Douglas production function presented in section 3

$$Y_t = L_t^{\alpha} K_t^{1-\alpha} P_t^{\gamma}$$

where, Y is total output, L is labor, K is capital stock and P is patent stocks which is substituted for x_i representing the new products in the Romer model. Taking the log of above function yields the following regression equation

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[8] This has also been confirmed by the Chow test. The results of Chow test reject the hypotheses that the coefficients are same across the samples used in the analysis.

$$Log(Y_t) = \alpha \, Log(L_t) + (1-\alpha) Log\,(K_t) + \gamma \, Log(P_t)\,.$$

In addition to the variables in the regression equation above, the secondary school enrollments, risk of expropriation and openness variables are included in the analysis as well. The secondary school enrollments are used as a proxy for human capital, the risk of expropriation index captures the overall institutional development of the countries, which takes higher values for lower risk of expropriation. The openness variable captures the effect of liberal trade policy on the output level of a country.

The regressions results obtained from the OLS estimation are reported in Table 8. As shown in the table, the coefficient of initial per capita GDP is positive and significant in all samples suggesting that the convergence theory does not hold across the countries in the sample.[9] Returns to investment are positive and significant in all groups, while returns to labor are significant only in the full sample and in countries with higher income and smaller market. Moreover, except for higher income countries with smaller market, the coefficient of patent stock is positive and significant in all samples with a magnitude ranging from 0.03 in full sample and less advanced countries to 0.12 in larger market countries with lower per capita income. The openness variable is significant and has expected sign in most of the samples, while human capital and risk of expropriation are significant only in the full sample and the large market countries, respectively.

Table 9 reports the results of fixed effects regression analysis. As observed from the table, once country fixed effects are taken into account, the coefficient of labor becomes significant in all samples. According to these results, labor has the highest return in smaller market countries, with a magnitude of 0.77; and it has the lowest returns in larger market countries with lower income, with a magnitude of 0.20. On the other hand, investment has the highest returns in smaller market countries with lower income, with a magnitude of 0.32, and it has the lowest returns in countries with smaller market and higher income, with a magnitude of 0.06. Total returns to these inputs range from 0.28 percent in large market countries with lower income to 1.07 percent in smaller market countries with lower income. These results

[9] The convergence theory has also been tested using the per capita growth rate of GDP as a dependent variable, and initial per capita GDP as one of the independent variables. Although, these results suggest convergence among the 20 OECD countries, the rate at which this convergence occurs is very small. See Table 3A in the appendix.

suggest that on average, countries with smaller market tend to have constant returns to labor and investment, while countries with larger market have less than 50 percent returns to these inputs.

As shown in Table 9, the coefficient of patent stock is positive and significant in most of the samples except for the countries with higher income and smaller market, and lower income and larger market. The magnitudes of returns to patents range from 0.19 percent in higher income countries with larger market, to 0.03 percent in less advanced countries. As observed from Table 10, dynamic panel data analysis also confirms that the coefficient of patent stock is positive and significant in the samples mentioned above, suggesting that these results are robust to different estimations.

However, as seen from Table 10, the coefficient of labor becomes insignificant in most of the samples, which might be due to the multicollinearity problem between employment and investment (the correlation coefficient between first difference of employment and investment equal to 0.64). To eliminate this problem the estimation is repeated by including the second difference of employment in the analysis. Results are reported in Table 11. As seen from the table, this specification improves the coefficient of labor substantially, while the coefficients of the rest of the variables remain the same. Similar to the fixed effects results, the returns to investment and labor range from 0.60 percent in countries with higher income and larger market, to 0.94 in countries with higher income and smaller market. Moreover, labor receives the highest returns in higher income countries, while investment receives the highest return in lower income countries regardless of the market size.[10]

In order to check the robustness of the results obtained from the estimation of production function, total factor productivity (TFP) growth has also been estimated. The advantage of estimating TFP growth over the production function is that it reduces the endogeneity problem by excluding labor and investment from the right hand side of the regression equation.[11] As Table 12 shows, the coefficient of patent stock is positive and significant in

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[10] As seen from Table 3A in the appendix, the production function has also been estimated for countries with larger and smaller markets and countries with higher and lower per capita income without dividing each sample further in different groups. The results of GMM estimation shows that the patent stock is positively associated with per capita GDP which confirms the results obtained with smaller samples.

[11] As explained in section 2, TFP growth has been calculated subtracting the contribution of labor and investment to GDP growth from the GDP growth. Therefore, economically the estimation of TFP growth is

the full sample, countries with higher income and smaller market, and in less advanced countries. These results strengthen the argument that invention has a positive effect on countries' growth rates and productivity growths.

In addition, the above analyses have been repeated using larger data, which include some non-OECD countries and three other OECD countries.[12] Table 13 reports the results of the fixed effects and dynamic panel data analyses for the full sample and non-OECD countries. As seen from the table, in both analyses the coefficient of patent stock is positive and significant; suggesting that the positive effects of invention on aggregate output can be observed in the majority of the countries, regardless of their market size or income level.

Finally, a simple causality test between GDP and patent stock has been conducted using the first lags of these variables. The results are reported in Table 5A in the appendix. As seen from the table, the coefficient of patent stock in GDP regression is positive and significant in all samples, while coefficient of GDP in patent regression is not significant in any of the samples. The analysis has also been conducted using longer lag lengths. However, the results obtained with longer lag lengths imply simultaneity between these variables. Nevertheless, inclusion of all the lags in the same regression might yield inaccurate results due to high correlation between these lags. Although the test does not identify the causality between GDP and patent stocks due to simultaneity between these variables, the results reported in Table 8A and the results of the dynamic panel data analysis imply that invention is one of the important determinants of GDP.

In summary, the results obtained in this section show that there is a positive and significant relationship between invention and per capita output growth. In all regressions, the returns to invention in terms of per capita output are highest in the countries with higher income and larger market, with the magnitude of around 0.13. The second highest returns to invention have been observed in countries with lower income and smaller markets, with the magnitude of around 0.07. Although, the full sample and the less advanced countries have

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equivalent to the estimation of production function, but technically it provides more robust results as it eliminates the potential endogeneity problem between output, labor and investment.

[12] These NON-OECD countries are Argentina, Brazil, China, Hon Kong, Indonesia, India, Malaysia, Philippines, Singapore, Venezuela and South Africa; and the other three OECD countries are Turkey, Mexico and Korea. The reason for not using this larger sample throughout the paper is because R&D data were available only for 20 OECD countries.

consistently positive and significant coefficient on patent stock, due to the correlation between error term and the regressors in these samples, suggested by sargan test, the results cannot be interpreted with a confident. In addition, there is some evidence that the countries with higher income and smaller market also have significant returns to their invention in terms of their per capita output growth, with a magnitude of around 0.03. The only countries that do not have significant returns to their invention in term of their output growth are the countries with lower income and larger market. Moreover, the analysis of TFP growth in terms of invention suggest that a one percent increase in invention is related to around 0.6 percent increase in TFP growth in the full sample, countries with higher income and smaller market and in less advanced countries.

In short, the results of the analysis of the relationship between invention and GDP show that invention has positive effect on per capita output growth, which supports the predictions of R&D based growth models.

6. Conclusion

The objective of this paper was to assess whether there is a significant relationship between countries' R&D efforts and their invention, and between invention and per capita output growth. In light of our analysis, we can conclude that countries with larger markets are able to increase their invention by investing in R&D, while there is no such evidence in the rest of the samples. In such countries, a one percent increase in R&D expenditure leads to around 0.17 percent increase in their invention. This result is consistent with theories emphasizing on the importance of size of the markets to attain high levels of invention. In particular, inventing activity is a long and costly process which involves high level of uncertainty. In order for firms to invest in such activity the expected returns to their invention should be high. In this respect, large market countries can provide higher returns for longer periods, and this provides better incentives for firms to invest in an inventing activity.

Although, only larger market countries can enjoy the significant returns to their R&D investment in terms of invention, the positive effects of invention on per capita output growth have been observed in larger groups of countries, regardless of their market size and income levels. Specifically, a one percent increase in inventions of high income countries with larger markets is associated with a 0.13 percent increase in their per capita output, while rest of the samples have on average 0.03 percent returns to the their invention.

To sum up, this paper provides empirical support to endogenous growth theories in that that invention is not exogenous to economies but can be created by investing in R&D sectors and human capital. The future extensions of this study will explore the two implications of this paper: first, the majority of countries might prefer to import technology from developed countries, which might be the reason for the lack of significant relationship between R&D and invention in most of the countries; second, the quality of invention might differ across countries.

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Figure 1: Log Per Capita Patents vs. Log Per Capita R&D Expenditure (Averages over 1981-1997)

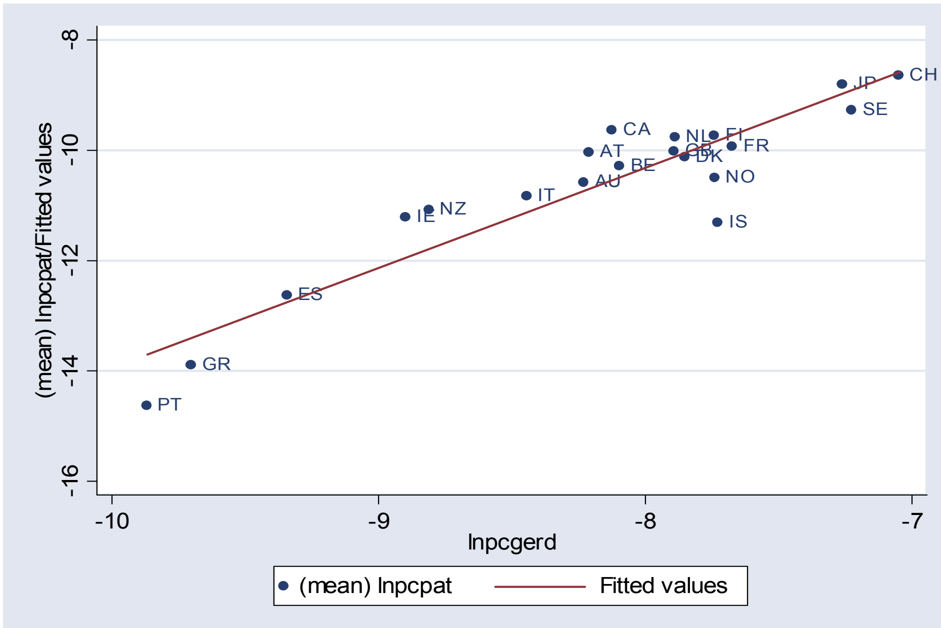


Figure 2: Log Per Capita GDP vs. Log Per Capita Patents (Averages over 1981-1997)

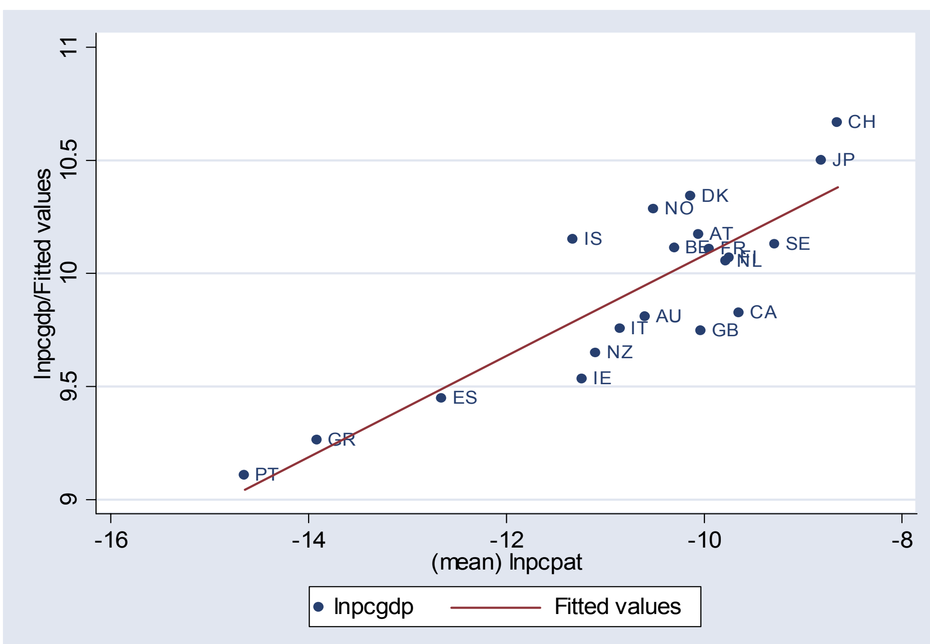


Figure 3: Time Series Plots of Per Capita Patent and Per Capita R&D Expenditure

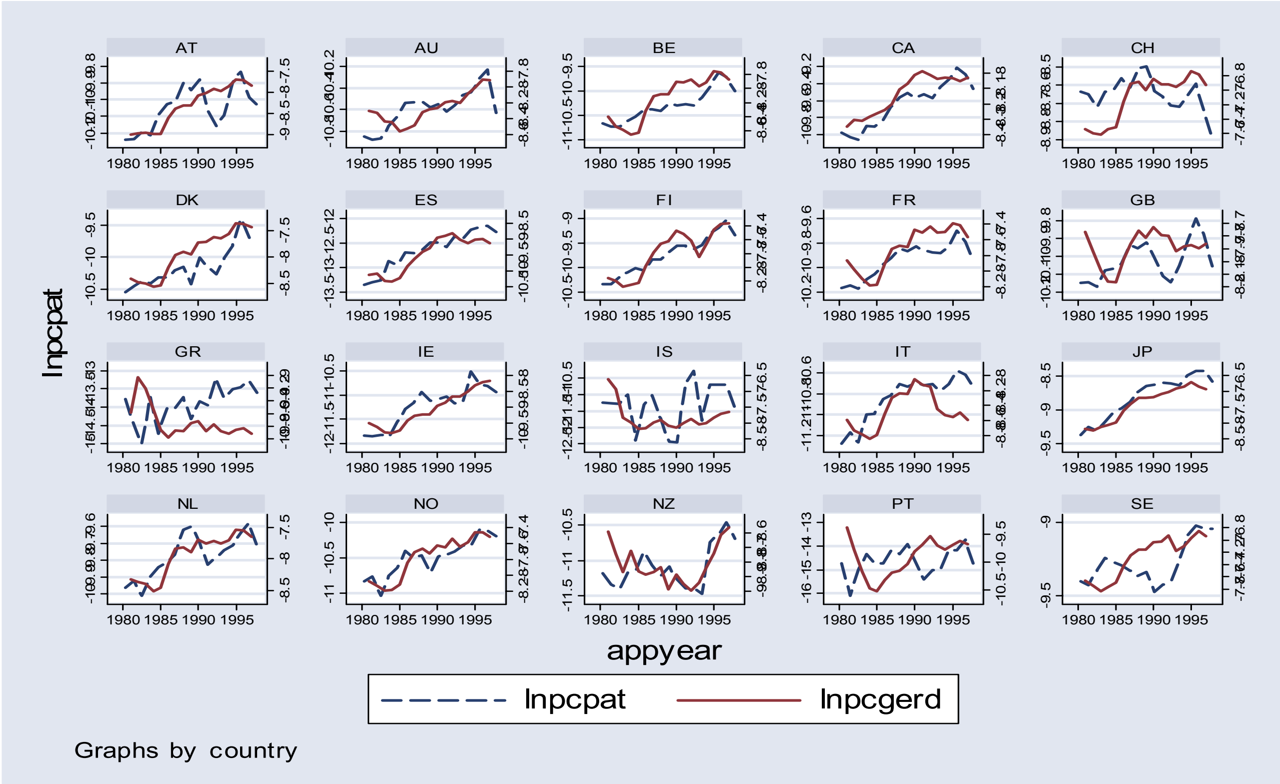


Figure 4: Time Series Plots of Per Capita GDP and Per Capita Patent Flows

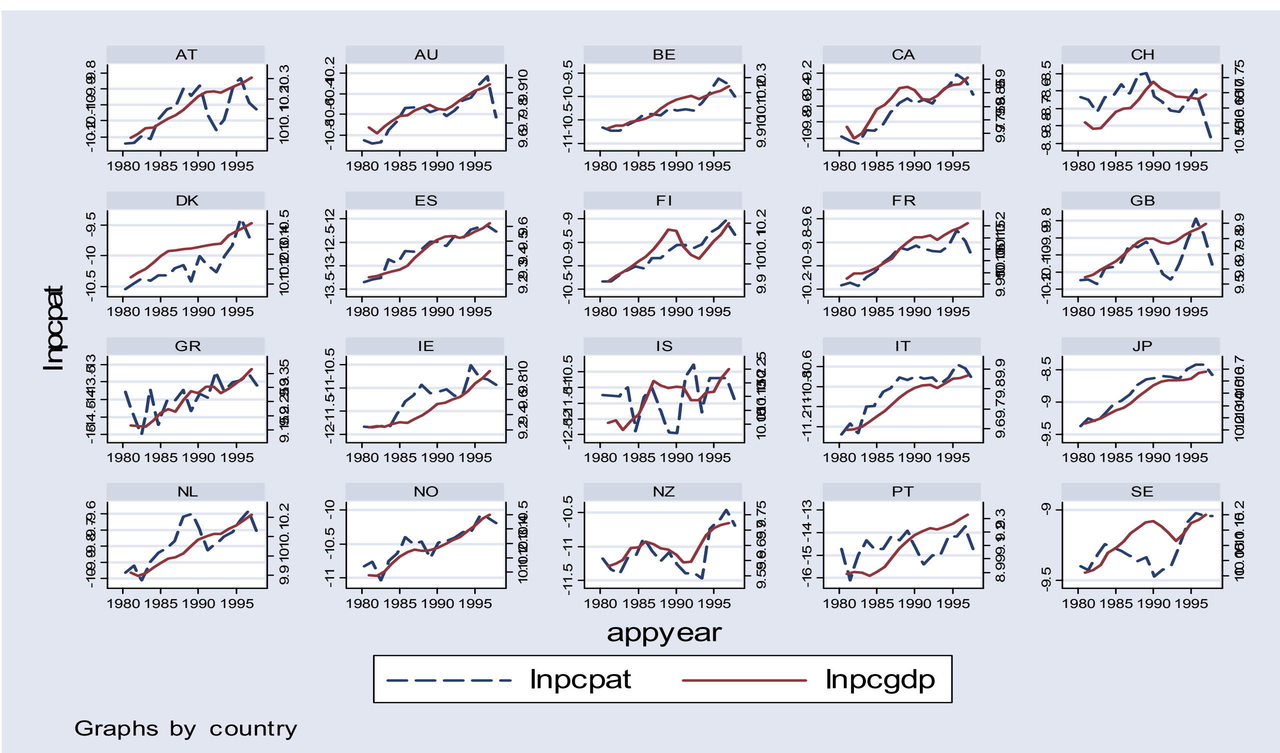
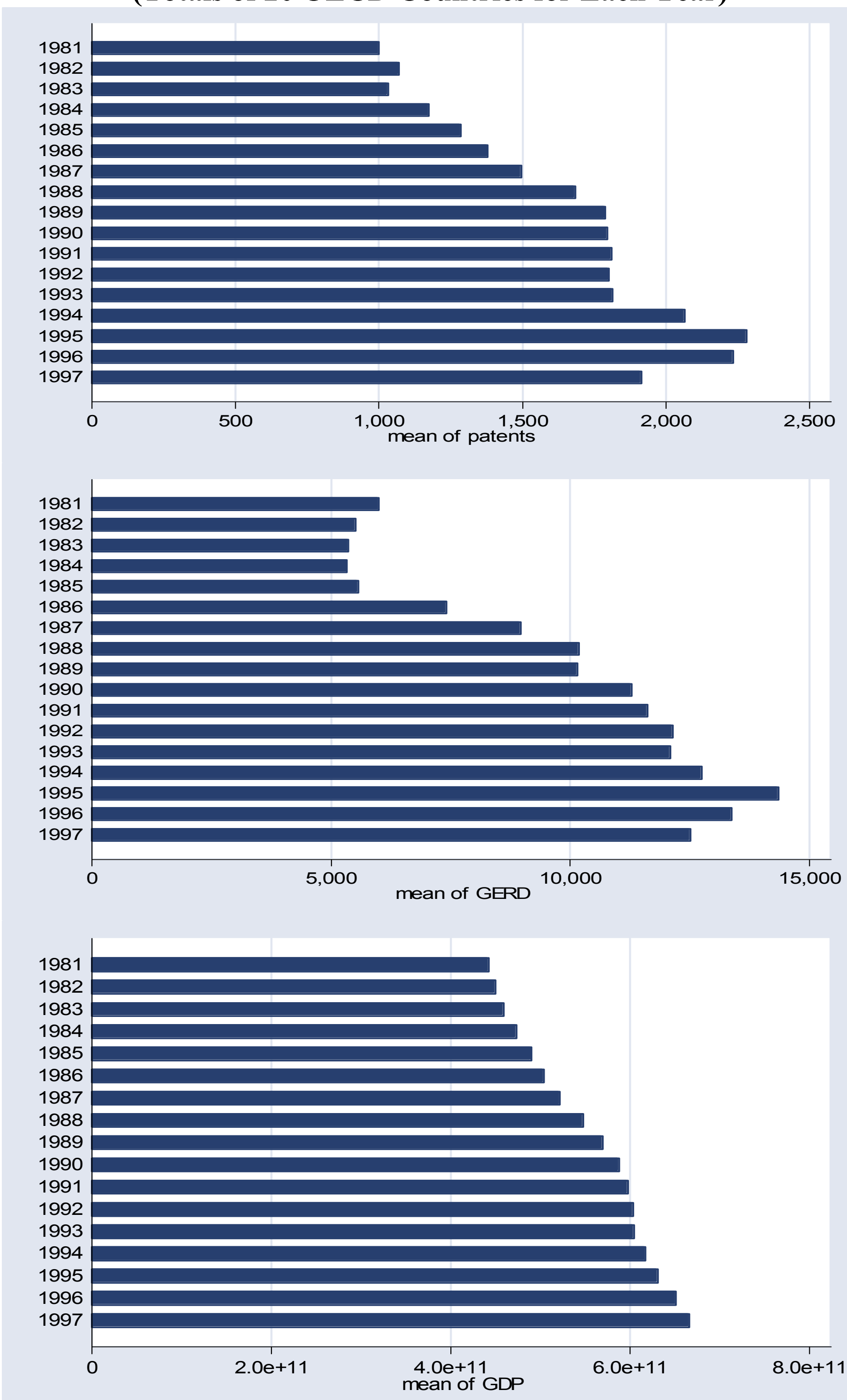


Figure 5: Total Amounts of Patents, R&D Expenditure, and GDP (Totals of 20 OECD Countries for Each Year)



Note: R&D expenditure and GDP are in 1995 constant $US.

Table 1: Ranking of Countries According GDP, Investment, Patents and R&D Expenditure[a]

Rank	Investment (Millions $US)		GDP (Million $US)		Patents		R&D Expenditure (Million $US)	
1	Japan	1244578	Japan	4442000	Japan	19286	Japan	86412
2	France	255983	France	1378000	France	2752	France	26271
3	Italy	180502	UK	980700	UK	2561	UK	21551
4	UK	155169	Italy	976700	Canada	1866	Italy	12255
5	Spain	96886	Canada	505700	Switzerland	1177	Canada	8134
6	Canada	91700	Spain	489000	Italy	1132	Sweden	6236
7	Netherlands	67539	Netherlands	346000	Netherlands	858	Switzerland	5825
8	Australia	64334	Australia	304100	Sweden	809	Netherlands	5599
9	Switzerland	59366	Switzerland	287200	Australia	433	Australia	4476
10	Austria	45149	Belgium	245100	Belgium	358	Spain	3395
11	Belgium	40851	Sweden	213700	Austria	339	Belgium	3048
12	Sweden	34507	Austria	202500	Finland	318	Finland	2169
13	Norway	31419	Denmark	159500	Denmark	217	Austria	2112
14	Finland	24781	Norway	123800	Spain	134	Denmark	2012
15	Denmark	23460	Finland	117100	Norway	121	Norway	1848
16	Greece	21340	Greece	106400	New Zealand	55	Greece	621
17	Portugal	20469	Portugal	89410	Ireland	51	Portugal	515
18	New Zealand	10094	New Zealand	52830	Greece	10	New Zealand	511
19	Ireland	8889	Ireland	48800	Portugal	5	Ireland	485
20	Iceland	1229	Iceland	6445	Iceland	4	Iceland	111

Source: GDP and Gross fixed investment (WDI 2002), R&D Expenditure (OECD), Patent Applications (U.S. Patent Office).

a.The averages are calculated for the period of 1981-1997. All series are in 95 constant US dollars.

Table 2: Ranking of Countries According to Per Capita GDP, Investment, Patents and R&D Expenditure[a]

Rank	Per Capita GDP		Per Capita Investment		Per Capita Patents (Per Million People)		Per Capita R&D Expenditure	
1	Switzerland	42824	Japan	10153	Switzerland	176	Switzerland	870
2	Japan	36138	Switzerland	8863	Japan	157	Sweden	730
3	Denmark	30889	Norway	7417	Sweden	95	Japan	705
4	Norway	29152	Austria	5823	Canada	68	France	466
5	Austria	26054	Finland	4980	Finland	64	Iceland	442
6	Iceland	25492	Iceland	4875	Netherlands	58	Norway	436
7	Sweden	24996	Denmark	4546	France	49	Finland	436
8	Belgium	24555	France	4539	UK	45	Denmark	390
9	France	24397	Netherlands	4536	Austria	44	Netherlands	376
10	Finland	23507	Belgium	4096	Denmark	42	UK	375
11	Netherlands	23173	Sweden	4039	Belgium	36	Belgium	306
12	Canada	18401	Australia	3842	Norway	29	Canada	297
13	Australia	18056	Canada	3347	Australia	26	Austria	272
14	Italy	17183	Italy	3177	Italy	20	Australia	267
15	UK	17040	New Zealand	2952	New Zealand	16	Italy	216
16	New Zealand	15423	UK	2700	Iceland	15	New Zealand	150
17	Ireland	13729	Ireland	2509	Ireland	14	Ireland	137
18	Spain	12617	Spain	2504	Spain	3	Spain	88
19	Greece	10487	Greece	2106	Greece	1	Greece	61
20	Portugal	9005	Portugal	2061	Portugal	1	Portugal	52

a. The averages are calculated for the period of 1981-1997. All series are in 95 constant US dollars.
Source: GDP and Gross fixed investment (WDI 2002), R&D Expenditure (OECD), Patent Applications (U.S. Patent Office).

Table 3: Pairwise Correlations and Summary Statistics

*significant at 10 percent level.

	R&D Exp	Patent	GDP	Invest ment	PC R&D Inv.	PC Patent	PC GDP	PC Invest.
R&D Exp	1.00							
Patents	0.98*	1.00						
GDP	0.99*	0.97*	1.00					
Investment	0.98*	0.99*	0.99*	1.00				
PC R&D Inv.	0.43*	0.42*	0.37	0.38*	1.00			
PC Patents	0.56*	0.59*	0.53*	0.54*	0.88*	1.00		
PC GDP	0.37	0.40*	0.34	0.36	0.88*	0.81*	1.00	
PC Investment	0.56*	0.60*	0.53*	0.58*	0.78*	0.79*	0.91*	1.00

	GDP	Initial GDP	Employ-ment	Invest-ment	Patent_2	School	Risk of Exprop.	Open-ness
GDP	1.00							
Initial GDP	0.95*	1.00						
Employment	0.67*	0.68*	1.00					
Investment	0.91*	0.87*	0.68*	1.00				
Patents_2	0.84*	0.84*	0.54*	0.72*	1.00			
Sec. School En.	0.45*	0.31*	0.07	0.33*	0.36*	1.00		
Risk of Exprop.	0.49*	0.34*	0.22*	0.42*	0.44*	0.55*	1.00	
Openness	0.59*	0.51*	0.15*	0.43*	0.59*	0.55*	0.52*	1.00

All variables except for risk of expropriation and openness are normalized by population and they are all in natural logs.

	PC Patent	R&D Expend_2	US Trade Share	Import/ Export	Corruption Index	School
PC Patent	1.00					
R&D Expend_2	0.55*	1.00				
US Trade Share	0.27*	0.02	1.00			
Import/Export	-0.38*	-0.58*	0.02	1.00		
Corruption Ind.	0.50*	-0.11*	0.31*	0.15*	1.00	
Sec. School En.	0.42*	0.07	0.03	-0.09*	0.29*	1.00

Note: “PC” in front of variables stands for “per capita”

Table 3 continued

	GDP Growth	Initial GDP	Employment Growth	Investment Growth	Patent Stock Growth	Patent Stock Growth _2	School Growth	Risk of Expropriation	Openness
GDP Growth	1.00								
Initial GDP	-0.14*	1.00							
Employment Growth	0.66*	-0.07	1.00						
Investment Growth	0.76*	-0.03	0.67*	1.00					
Patent Stock Growth	0.76*	-0.03	0.67*	1.00	1.00				
Patent Stock Growth _2	0.17*	-0.04	0.08	0.07	0.07	1.00			
Sec. School Enr. Growth	-0.08	-0.16*	-0.15*	-0.08	-0.08	-0.08	1.00		
Risk of Expropriation	0.03	0.34*	-0.01	0.10*	0.10*	0.20*	0.01	1.00	
Openness	0.14*	0.51*	-0.02	0.00	0.004	0.16*	-0.101*	0.52*	1.00

All variables except for risk of expropriation and openness are in per-capita terms.

Table 4: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Minimum	Maximum
Log PC GDP	340	9.926	.410	8.874	10.73
Log Initial PC GDP	340	9.778	.407	8.888	10.60
Log Employment/Pop	340	-.8509	.158	-1.238	-.558
Log PC Investment	340	8.29	.460	7.188	9.460
Log PC Patent St_2	300	-9.188	1.510	-13.35	-6.945
Log Secondary School Enrollments	340	4.594	.183	3.621	5.028
Risk of Expropriation	340	9.384	.998	4.25	10
Openness	340	.0045	.045	-.2298	.126
PC GDP Growth	320	.0190	.022	-.0788	.102
PC Employment Growth	320	.0012	.018	-.0792	.0461
PC Inv. Growth	320	.0169	.069	-.2318	.227
PC Patent Stock Growth	320	.0168	.069	-.2318	.227
PC Patent Stock_2 Growth	280	.0329	.061	-.164	.355
Secondary School Enr. Growth	320	.020	.049	-.128	.455
Risk of expropriation	340	9.383	.998	4.25	10
Openness	340	.0045	.045	-.229	.126
Log PC Patent	340	-10.65	1.538	-16.109	-8.41
Log R&D Exp. Stock	300	9.451	1.490	6.262	13.21
Log US Trade Share	340	-16.99	.742	-18.334	-14.47
Log Import/Export	340	.224	.7548	-1.763	2.607
Log Corruption Index	340	1.658	.1689	1.098	1.819

Note: “PC” in front of variables stands for “per capita”

Table 5: Pooled OLS Regression Analysis of Per Capita Patents (1983-1997)

	Full Sample (1)	Higher Income & Smaller Market Countries (2)	Lower Income & Larger Market Countries (3)	Higher Income & Larger Market Countries (4)	Lower Income& Smaller Market Countries (5)	Less Advanced Countries (6)
Initial Patents	1.053	0.863	0.735	0.919	0.820	1.071
	(33.9)**	(5.03)**	(22.73)**	(31.35)**	(4.95)**	(16.45)**
R&D Expenditure_2	-0.001	0.105	0.109	0.264	-0.401	-0.069
	(0.04)	(1.42)	(2.29)*	(4.43)**	(2.73)**	(0.97)
Corruption Index	0.138	1.290	0.318	-0.158	-0.654	0.007
	(0.80)	(1.48)	(2.93)**	(0.86)	(1.70)	(0.04)
Human Capital	-0.136	0.158	-0.128	1.317	-0.133	-0.388
	(0.65)	(0.24)	(1.23)	(5.97)**	(0.28)	(1.49)
Import/Export	-0.182	0.024	-0.001	0.087	0.308	-0.112
	(3.43)**	(0.16)	(0.02)	(0.79)	(1.18)	(1.16)
US Trade Share/GDP	0.022	-0.407	0.086	0.380	0.674	0.207
	(0.59)	(2.23)*	(3.51)**	(3.29)**	(2.07)*	(1.71)
Constant	1.912	0.000	-2.051	0.000	0.000	0.000
	(1.30)	(.)	(2.00)*	(.)	(.)	(.)
R-Squared	0.99	0.99	0.99	0.99	0.99	0.99
Observations	300	90	90	60	60	150
# of Country	20	6	6	4	4	10

z statistics corrected for first order autocorrelations using Cochrane-Orcutt transformation method are in parentheses.
* significant at 5%; ** significant at 1%.
All variables are in natural logs, and all regression analyses include time dummies.
a. This sample is constructed by dropping the first five countries in the ranking of aggregate and per capita GDP to observe the nature of the relationship between R&D and invention in countries having lower and middle range of per capita income and market size.

Table 6: Fixed Effects Regression Analysis of Per Capita Patents (1983-1997)

	Full Sample (1)	Higher Income & Smaller Market Countries (2)	Lower Income & Larger Market Countries (3)	Higher Income & Larger Market Countries (4)	Lower Income& Smaller Market Countries (5)	Less Advanced Countries (6)
Patents_1	0.234	0.177	0.557	0.803	0.199	0.286
	(4.44)**	(1.73)	(8.48)**	(13.19)**	(1.77)	(4.16)**
R&D Expenditure_2	0.022	0.025	0.173	0.077	0.071	0.059
	(0.39)	(0.27)	(3.46)**	(0.89)	(0.26)	(0.60)
Corruption Index	0.021	0.305	0.220	0.013	-0.535	-0.046
	(0.15)	(0.22)	(3.44)**	(0.13)	(1.06)	(0.30)
Human Capital	-0.297	-0.725	0.033	0.451	-0.113	-0.224
	(1.90)	(1.31)	(0.57)	(3.90)**	(0.21)	(1.13)
Import/Export	0.252	0.672	0.059	0.084	0.557	0.258
	(3.11)**	(2.92)**	(1.66)	(1.15)	(1.69)	(2.27)*
US Trade Share/GDP	0.083	-0.153	0.117	0.045	0.462	0.307
	(0.91)	(0.72)	(2.58)**	(0.38)	(1.21)	(2.38)*
Constant	-4.956	-8.142	0.000	-3.919	0.000	0.000
	(2.73)**	(1.72)	(.)	(1.63)	(.)	(.)
R-Squared	0.99	0.99	0.99	0.99	0.99	0.99
Observations	300	90	90	60	60	150
# of Country	20	6	6	4	4	10

z statistics corrected for first order autocorrelations using Cochrane-Orcutt transformation method are in parentheses.
* significant at 5%; ** significant at 1%.
All variables are in natural logs. All regression analyses include time dummies.

Table 7: Dynamic Panel Data Analysis of Per Capita Patents (1983-1997)

	Full Sample (1)	Higher Income & Smaller Market Countries (2)	Lower Income & Larger Market Countries (3)	Higher Income & Larger Market Countries (4)	Lower Income& Smaller Market Countries (5)	Less Advanced Countries (6)
Per Capita Patents_1	0.220	0.209	0.543	0.779	0.113	0.179
	(3.46)**	(1.70)	(5.53)**	(8.29)**	(0.74)	(2.13)*
R&D Expenditure_2	0.050	-0.052	0.164	0.049	0.141	0.136
	(0.63)	(0.42)	(1.82)	(0.35)	(0.41)	(1.19)
Corruption Index	-0.174	0.346	0.236	-0.000	-0.311	-0.033
	(0.86)	(0.20)	(2.02)*	(0.00)	(0.43)	(0.14)
Human Capital	-0.148	-0.264	0.053	0.429	-0.281	-0.243
	(0.66)	(0.47)	(0.48)	(2.37)*	(0.39)	(0.96)
Import/Export	0.358	0.505	0.081	0.127	0.507	0.308
	(3.10)**	(1.74)	(1.17)	(1.08)	(1.14)	(2.02)*
US Trade Share/GDP	-0.080	-0.032	0.128	0.058	0.353	0.123
	(0.57)	(0.13)	(1.56)	(0.34)	(0.67)	(0.70)
Constant	0.033	0.034	0.018	-0.005	0.107	0.017
	(3.22)**	(1.38)	(2.88)**	(0.51)	(4.17)**	(1.37)
Observations	280	84	84	56	56	140
# of Country	20	6	6	4	4	10
Sargan Test[a] (*p-value*)	0.0	1	1	1	1	0.72
Serial Correlation Test[b] (*p-value*)	0.94	0.22	0.16	0.58	0.35	0.02

Z statistics corrected for first order autocorrelations are in parentheses.
* significant at 5%; ** significant at 1%.
a. H_0: regressors are not correlated with the residuals
b. H_0: errors in first difference regression exhibit no second order serial correlation.
All variables are in natural logs and differenced once, except for lagged dependent variable; all regressions include time dummies.

Table 8: Pooled OLS Regression Analysis of Per Capita GDP (1983-1997)

	Full Sample (1)	Higher Income & Smaller Market Countries (2)	Lower Income & Larger Market Countries (3)	Higher Income & Larger Market Countries (4)	Lower Income& Smaller Market Countries (5)	Less Advanced Countries (6)
Initial Per Capita GDP	0.616	1.189	0.326	0.343	0.250	0.558
	(25.36)**	(10.11)**	(2.93)**	(5.57)**	(1.87)	(8.86)**
Employment	0.142	0.714	-0.011	-0.004	0.100	0.013
	(3.52)**	(7.09)**	(0.19)	(0.03)	(0.78)	(0.25)
Investment	0.200	0.074	0.233	0.166	0.324	0.259
	(13.52)**	(3.41)**	(7.87)**	(4.67)**	(5.46)**	(10.33)**
Patent Stock_2	0.025	0.004	0.058	0.121	0.054	0.030
	(5.17)**	(0.20)	(2.93)**	(4.74)**	(1.80)	(2.21)*
Human Capital	0.030	0.091	-0.020	0.055	0.083	0.037
	(1.69)	(2.36)*	(1.20)	(1.89)	(1.68)	(1.61)
Risk of Expropriation	0.009	0.015	0.005	0.010	0.001	0.005
	(2.68)**	(1.80)	(1.01)	(0.98)	(0.12)	(1.29)
Openness [(X+M)/GDP]	0.237	0.173	0.154	-0.288	0.431	0.408
	(3.84)**	(2.25)*	(1.17)	(1.10)	(2.04)*	(3.77)**
Constant	0.000	-2.263	5.216	5.943	0.000	0.000
	(.)	(1.94)	(4.30)**	(5.80)**	(.)	(.)
R-Squared	0.99	0.99	0.99	0.99	0.99	0.99
Observations	300	90	90	60	60	150
# of country	20	6	6	4	4	10

z statistics corrected for first order autocorrelations using Cochrane-Orcutt transformation method are in parentheses.
* significant at 5%; ** significant at 1%.
All variables except for openness and risk of expropriation are normalized by population and they are all in natural logs.
All regression analyses include time dummies.

Table 9: Fixed Effects Regression Analysis of Per Capita GDP (1983-1997)

	Full Sample (1)	Higher Income & Smaller Market Countries (2)	Lower Income & Larger Market Countries (3)	Higher Income & Larger Market Countries (4)	Lower Income& Smaller Market Countries (5)	Less Advanced Countries (6)
Employment	0.415	0.751	0.274	0.194	0.772	0.485
	(7.72)**	(7.03)**	(3.92)**	(2.13)*	(4.24)**	(7.21)**
Investment	0.171	0.043	0.211	0.086	0.318	0.185
	(8.78)**	(1.49)	(7.19)**	(2.68)**	(4.73)**	(6.42)**
Patent Stock_2	0.088	0.039	0.018	0.190	0.150	0.135
	(7.18)**	(2.09)*	(0.83)	(12.43)**	(4.31)**	(7.50)**
Human Capital	0.046	0.046	-0.012	0.023	0.024	0.073
	(2.99)**	(1.21)	(0.80)	(1.39)	(0.60)	(3.89)**
Risk of Expropriation	0.011	0.006	0.010	0.012	0.004	0.010
	(3.87)**	(0.66)	(2.26)*	(1.49)	(0.74)	(3.31)**
Openness [(X+M)/GDP]	0.198	0.068	0.263	-0.333	1.153	0.482
	(3.00)**	(0.74)	(2.12)*	(1.94)	(5.56)**	(4.23)**
Constant	0.000	10.537	8.374	11.159	9.299	9.565
	(.)	(30.48)**	(21.40)**	(34.97)**	(13.09)**	(26.87)**
R-Squared	0.99	0.99	0.99	0.99	0.99	0.99
Observations	300	90	90	60	60	150
# of country	20	6	6	4	4	10

z statistics corrected for first order autocorrelations using Cochrane-Orcutt transformation method are in parentheses.
* significant at 5%; ** significant at 1%

Table 10: GMM Dynamic Panel Data Analysis of Per Capita GDP

	Full Sample (1)	Higher Income & Smaller Market Countries (2)	Lower Income & Larger Market Countries (3)	Higher Income & Larger Market Countries (4)	Lower Income& Smaller Market Countries (5)	Less Advanced Countries (6)
1^{st} Lag of Per Capita GDP	0.690	0.610	0.492	0.507	0.666	0.667
	(19.37)**	**(8.90)****	**(9.11)****	**(3.06)****	**(7.37)****	**(14.34)****
Employment	-0.071	0.350	0.223	-0.081	0.004	0.057
	(1.76)	**(3.94)****	**(4.07)****	(0.59)	(0.02)	(1.18)
Investment	0.150	0.024	0.169	0.053	0.248	0.157
	(9.30)**	(1.14)	**(5.97)****	(1.49)	**(4.74)****	**(7.69)****
Patent Stock_2	0.074	0.039	0.015	0.096	0.076	0.055
	(7.48)**	**(2.58)****	(1.14)	**(2.45)***	**(2.93)****	**(4.00)****
Human Capital	-0.004	0.044	0.024	0.017	-0.015	-0.009
	(0.35)	(1.57)	(2.25)*	(0.77)	(0.54)	(0.64)
Risk of Expropriation	0.009	-0.008	0.007	0.000	0.004	0.009
	(4.65)**	(1.25)	**(1.76)**	(0.00)	(1.06)	**(3.93)****
Openness[(X+M)/GDP]	0.386	0.184	0.467	-0.271	0.810	0.729
	(6.79)**	**(2.27)***	**(4.34)****	**(1.35)**	**(4.63)****	**(9.75)****
Constant	-0.000	0.007	0.003	0.001	-0.001	-0.001
	(0.14)	(3.64)**	(2.93)**	(0.65)	(0.66)	(0.82)
Observations	280	84	84	56	56	140
# of countries	20	6	6	4	4	10
Sargan Test[a] (*p-value*)	0.00	0.56	0.16	1.00	1.00	0.00
Serial Correlation Test[b] (*p-value*)	0.07	0.06	0.49	0.09	0.67	0.53

Z statistics are in parentheses.
* significant at 5%; ** significant at 1%.
a.H_0: regressors are not correlated with the residuals
b. H_0: errors in first difference regression exhibit no second order serial correlation.
All variables except for openness and risk of expropriation are normalized by population and in natural logs.
GMM estimator uses the first differences of variables and includes lagged dependent variable in the analysis.
All regressions include time dummies.

Table 11: GMM Dynamic Panel Data Analysis of Per Capita GDP (1983-1997)

	Full Sample (1)	Higher Income & Smaller Market Countries (2)	Lower Income & Larger Market Countries (3)	Higher Income & Larger Market Countries (4)	Lower Income& Smaller Market Countries (5)	Less Advanced Countries (6)
Per Capita GDP_1	0.761	0.793	0.646	0.355	0.710	0.767
	(23.33)**	(16.47)**	(11.66)**	(2.96)**	(9.22)**	(18.77)**
Employment	0.517	0.840	0.454	0.554	0.523	0.415
	(10.03)**	(9.93)**	(5.82)**	(2.77)**	(3.14)**	(5.86)**
Investment	0.081	0.032	0.158	0.040	0.179	0.113
	(5.16)**	(2.08)*	(5.43)**	(1.44)	(3.39)**	(5.38)**
Patent Stock_2	0.057	0.019	0.002	0.133	0.065	0.036
	(5.89)**	(1.51)	(0.11)	(4.11)**	(2.36)*	(2.88)**
Human Capital	0.013	0.029	0.019	0.013	0.031	0.004
	(1.21)	(1.28)	(1.70)	(0.72)	(0.97)	(0.31)
Risk of Expropriation	0.007	-0.008	0.000	0.002	0.009	0.008
	(3.33)**	(1.41)	(0.01)	(0.30)	(2.01)*	(3.62)**
Openness[(X+M)/GDP]	0.313	0.098	0.432	-0.159	0.760	0.595
	(5.60)**	(1.40)	(3.80)**	(0.87)	(4.15)**	(7.52)**
Constant	0.000	0.003	0.001	0.002	-0.003	-0.001
	(0.01)	(2.20)*	(1.40)	(1.45)	(1.63)	(1.88)
Observations	280	84	84	56	56	140
# of countries	20	6	6	4	4	10
Sargan Test[a] (*p-value*)	0.00	0.99	0.91	1.00	1.00	0.03
Serial Correlation Test[b] (*p-value*)	0.17	0.76	0.50	0.05	0.68	0.73

Z statistics are in parentheses.
* significant at 5%; ** significant at 1%.
a. H_0: regressors are not correlated with the residuals
b. H_0: errors in first difference regression exhibit no second order serial correlation.
All variables except for openness and risk of expropriation are normalized by population and in natural logs.
GMM estimator uses the first differences of the series and includes lagged dependent variable in the analysis. In the above regression employment is differenced twice.
All regressions include time dummies.

Table 12: Pooled OLS Regression Analysis of TFP Growth (1983-1997)

	Full Sample (1)	Higher Income & Smaller Market Countries (2)	Lower Income & Larger Market Countries (3)	Higher Income & Larger Market Countries (4)	Lower Income& Smaller Market Countries (5)	Less Advanced Countries (6)
Patent Stock Growth_2	0.043	0.054	-0.031	0.040	0.033	0.074
	(1.96)	(1.77)	(0.39)	(0.92)	(0.58)	(1.85)
Human Capital Stock Growth	-0.001	0.014	-0.022	-0.021	-0.005	-0.014
	(0.05)	(0.14)	(1.28)	(0.70)	(0.05)	(0.37)
Risk of Expropriation	-0.069	0.026	-0.122	-0.121	-0.029	-0.062
	(5.11)**	(0.45)	(3.55)**	(1.95)	(0.93)	(3.67)**
Openness[(X+M)/GDP]	0.157	0.283	0.076	-0.189	0.154	0.126
	(4.79)**	(2.71)**	(0.94)	(1.44)	(3.14)**	(3.14)**
Constant	0.166	-0.055	0.271	0.294	0.072	0.140
	(5.72)**	(0.44)	(3.62)**	(2.05)*	(1.02)	(3.60)**
Observations	280	84	84	56	56	140
# of countries	20	6	6	4	4	10
R-squared	0.27	0.41	0.49	0.49	0.37	0.33

Robust t statistics in parentheses
* significant at 5%; ** significant at 1%
All regressions include time dummies.

Table 13: Analysis of Per Capita GDP Using OECD and Non-OECD Samples (1983-1997)

	Full Sample (Includes both OECD and Non-OECD)		Only Non-OECD Sample		
	Fixed Effects	**GMM**	**Fixed Effects**	**GMM**	**GMM**
Employment	-0.035	0.121	0.234	-0.115	0.091
	(0.70)	(2.00)*	(1.27)	(0.65)	(0.50)
Investment	0.299	0.204	0.340	0.184	0.258
	(27.10)**	(10.84)**	(20.14)**	(8.24)**	(15.20)**
Patent Stock_2	0.101	0.064	0.113	0.080	0.005
	(12.64)**	(5.74)**	(6.85)**	(4.84)**	(0.23)
Human Capital	0.013	0.022	-0.069	-0.033	0.003
	(0.81)	(2.80)**	(2.02)*	(1.29)	(0.08)
Risk of Expropriation	-0.002	0.001	0.003	0.007	0.004
	(0.94)	(0.40)	(0.95)	(2.46)*	(1.52)
Opennes [(X+M)/GDP]	0.000	0.000	0.001	-0.000	0.002
	(1.87)	(0.99)	(3.62)**	(0.55)	(2.76)**
GDP_1	--	0.345	--	0.556	0.949
		(3.62)**		(10.37)**	(51.63)**
Constant	7.951	0.006	0.000	0.002	0.002
	(46.10)**	(3.95)**	(.)	(1.20)	(2.24)*
R-Squared	0.99	--	0.99	--	--
Observations	479	446	149	139	129
Number of country1	33	33	10	10	10
Sargan Test[a] (p-value)	--	1.00	--	0.00	0.78
Serial Correlation Test[b] (p-value)	--	0.45	--	0.13	0.27

z statistics in parentheses
* significant at 5%; ** significant at 1%
All variables except for risk of expropriation and openness are normalized by population and are in natural logs.
All regressions include time dummies

Appendix: Regression Tables

Table 1A: Dynamic Panel Data Analysis of Per Capita Patents Using Larger Samples[a]

	Larger Market Countries	Smaller Market Countries	Higher Income Countries	Lower Income Countries	Non-G7 Countries	G-7 Countries
Per Capita Patents	0.639	0.148	0.235	0.094	0.230	0.497
	(8.88)**	(1.52)	(2.59)**	(1.05)	(3.16)**	(4.00)**
D.R&D Expenditure_2	0.164	-0.055	-0.089	0.166	0.113	0.119
	(2.59)**	(0.39)	(0.98)	(1.52)	(1.13)	(1.40)
D.Corruption index	0.183	-0.425	0.064	0.133	-0.233	0.152
	(2.21)*	(0.95)	(0.17)	(0.61)	(0.90)	(1.71)
D.Human Capital	0.166	-0.550	0.555	-0.553	-0.264	0.014
	(1.88)	(1.29)	(1.62)	(2.14)*	(0.96)	(0.12)
D. Import/Export	0.055	0.319	0.536	0.126	0.448	0.154
	(1.07)	(1.55)	(2.93)**	(0.82)	(3.10)**	(1.52)
D.US Trade Share	0.097	-0.055	-0.250	-0.121	-0.104	0.184
	(1.45)	(0.22)	(1.12)	(0.73)	(0.58)	(3.08)**
Constant	-0.019	0.023	0.018	0.075	0.034	-0.005
	(4.27)**	(1.42)	(1.41)	(6.01)**	(2.61)**	(0.68)
Observations	126	126	126	126	210	70
# of Country	9	9	9	9	15	5
Sargan Test[b] (p-value)	0.99	0.78	0.81	0.81	0.01	1.00
Serial Correlation Test[c] (p-value)	0.16	0.71	0.09	0.06	0.96	0.02

Absolute value of z statistics in parentheses

* significant at 5%; ** significant at 1%

a. These samples are same samples as those reported in the paper. The only difference is that they are not subdivided among themselves, i.e. the large market countries include all countries with larger market regardless of their income level, and the higher income countries include all high income countries regardless of their market size. This analysis is useful to check the results obtained previously, as it provides us with larger samples.

b..H_0: regressors are not correlated with the residuals c. H_0: errors in first difference regression exhibit no second order serial correlation.

All regressions include time dummies.

Note: The letter "D" in front of variable names shows that the series have been log differenced once.

Table 2A: Causality Test Using Fixed Effects Regression: Per Capita Patents vs. R&D Expenditure

	One Lags Included		Two Lags Included		Three Lags Included	
	Per Capita Patent	R&D Expenditure	Per Capita Patent	R&D Expenditure	Per Capita Patent	R&D Expenditure
Per Capita Patent_1	0.712 (11.25)**	-0.003 (0.12)	0.351 (3.45)**	0.019 (0.62)	0.183 (1.66)	0.009 (0.27)
R&D Expenditure_1	0.110 (2.75)**	0.934 (31.22)**	0.106 (0.62)	1.711 (23.71)**	-0.355 (1.20)	1.935 (19.71)**
Per Capita Patent_2	--	--	0.263 (2.82)**	0.025 (0.86)	0.276 (2.62)**	0.005 (0.15)
R&D Expenditure_2	--	--	0.024 (0.14)	-0.776 (10.76)**	1.105 (2.01)*	-1.228 (6.68)**
Per Capita Patent_3	--	--	--	--	0.043 (0.43)	-0.002 (0.06)
R&D Expenditure_3	--	--	--	--	-0.605 (1.96)*	0.236 (2.32)*
Constant	-4.732 (4.16)**	0.000 (.)	-6.147 (4.40)**	1.159 (2.53)*	0.000 (.)	0.000 (.)
R-Squared	0.99	0.99	0.99	0.99	0.99	0.99
Observations	96	96	90	90	84	84
# of country	6	6	6	6	6	6

Table 3A: Pooled OLS Regression Analysis of Per Capita GDP Growth

	Full Sample	Higher Income & Smaller Market Countries	Lower Income & Larger Market Countries	Higher Income & Larger Market Countries	Lower Income& Smaller Market Countries	Less Advanced Countries
Initial Per Capita GDP	-0.014	-0.043	-0.013	-0.002	-0.054	-0.022
	(5.45)**	(2.74)**	(1.81)	(0.26)	(5.32)**	(5.30)**
D. Employment	0.342	0.522	0.355	0.035	0.251	0.200
	(5.05)**	(4.80)**	(3.41)**	(0.16)	(1.49)	(2.23)*
D. Investment	0.173	0.123	0.176	0.191	0.218	0.194
	(10.37)**	(4.23)**	(6.09)**	(3.14)**	(5.32)**	(8.71)**
D. Patent Stock_2	0.033	0.006	-0.043	0.147	0.020	0.046
	(2.62)**	(0.35)	(0.81)	(3.31)**	(0.54)	(2.04)*
D. Human Capital	0.011	0.032	-0.000	-0.002	-0.067	0.022
	(0.68)	(1.04)	(0.02)	(0.11)	(1.23)	(1.17)
Risk of Expropriation	-0.017	0.002	-0.025	0.000	-0.007	-0.018
	(1.63)	(0.05)	(1.15)	(0.01)	(0.34)	(1.46)
Openness [(X+M)/GDP]	0.178	0.250	0.056	-0.166	0.254	0.202
	(6.74)**	(4.66)**	(0.90)	(1.39)	(6.64)**	(5.74)**
Constant	0.194	0.443	0.192	0.029	0.539	0.268
	(7.17)**	(2.70)**	(2.58)*	(0.19)	(5.13)**	(6.21)**
Observations	280	84	84	56	56	140
R-squared	0.74	0.84	0.78	0.83	0.83	0.79

Robust t statistics in parentheses
* significant at 5%; ** significant at 1%
All regressions include time dummies
Note: The letter "D" in front of variable names shows that the series have been log differenced once.

Table 4A. GMM Dynamic Panel Data Analysis of Per Capita GDP Using Larger Samples[a]

	Larger Market Countries	Smaller Market Countries	Higher Income Countries	Lower Income Countries	Non-G7 Countries	G-7 Countries
D2. Employment	0.412	0.644	0.813	0.409	0.467	0.600
	(4.29)**	(7.80)**	(10.35)**	(5.41)**	(6.18)**	(4.39)**
D.Investment	0.104	0.062	0.024	0.161	0.056	0.128
	(3.85)**	(3.03)**	(1.70)	(5.80)**	(3.03)**	(2.51)*
D.Patent Stock_2	0.025	0.027	0.031	0.046	0.049	0.048
	(1.75)	(2.06)*	(3.35)**	(2.86)**	(4.28)**	(2.89)**
D.Human Capital	0.040	-0.003	0.034	0.015	0.002	0.068
	(3.78)**	(0.16)	(2.35)*	(1.09)	(0.12)	(3.54)**
D.Risk of Expropriation	-0.001	0.007	-0.006	0.007	0.006	0.006
	(0.18)	(2.48)*	(1.55)	(3.07)**	(2.64)**	(0.79)
D.openness	0.196	0.397	0.077	0.654	0.324	0.240
	(1.85)	(5.54)**	(1.22)	(7.35)**	(4.84)**	(1.81)
Per Capita GDP_1	0.916	0.844	0.803	0.731	0.912	0.655
	(9.65)**	(21.23)**	(19.73)**	(16.70)**	(12.62)**	(9.89)**
Constant	0.005	0.001	0.002	-0.002	0.010	0.000
	(1.06)	(0.64)	(2.15)*	(2.70)**	(2.21)*	(0.11)
Observations	117	126	126	126	210	70
# of country	9	9	9	9	15	5
Sargan Test[b] (p-value)	0.45	0.80	0.50	0.33	0.15	1.00
Serial Correlation Test[c] (p-value)	0.56	0.54	0.43	0.98	0.42	0.08

z statistics are in parenthesis.

b..H_0: regressors are not correlated with the residuals

c. H_0: errors in first difference regression exhibit no second order serial correlation

All variables except for risk of expropriation and openness are normalized by population and are in natural logs. The letter "D" shows that the series are differenced once, "D2" shows that the series are differenced twice. All regressions include time dummies.

Table 5A. Causality Test Using Fixed Effects Regression: Per Capita GDP vs. Per Capita Patent Stock

	Full Sample		Less Advanced Countries		Lower income & smaller market		Higher income & Larger market		Higher Income & Smaller Market	
	GDP	Patent	GDP	Patent	GDP	Patent	GDP	Patent	GDP	Patent
GDP_1	0.897	-0.034	0.970	-0.103	1.010	-0.089	0.548	-0.069	0.765	0.069
	(31.82)**	(0.50)	(27.11)**	(1.46)	(23.61)**	(0.70)	(6.11)**	(0.36)	(11.72)**	(0.35)
Patent Stock_1	0.030	0.830	0.044	0.870	0.062	0.825	0.115	0.960	-0.005	0.770
	(3.04)**	(29.68)**	(2.83)**	(27.38)**	(2.81)**	(12.87)**	(4.72)**	(18.03)**	(0.28)	(12.86)**
Constant	1.331	-1.067	0.880	-0.711	0.727	0.000	0.000	0.415	0.000	-2.605
	(4.11)**	(1.35)	(1.93)	(0.82)	(1.19)	(.)	(.)	(0.17)	(.)	(1.29)
R-Squared	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Observations	320	320	160	160	64	64	64	64	96	96
# of country	20	20	10	10	4	4	4	4	6	6

z statistics in parentheses
* significant at 5%; ** significant at 1%
All variables are in natural logs. All regressions include time dummies.